ANL/APS/TB-13

Report on the Value Engineering Workshop on APS Beamline Front Ends

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Executive Summary

A formal value engineering evaluation process was developed to address the front end components of the beamlines for the Advanced Photon Source (APS). This process (described in Section 2) involved an information phase, a creative phase, a judgment phase, a development phase, and a recommendation phase. Technical experts from other national laboratories and industry were invited to a two-day Value Engineering Workshop on November 5-6, 1992. The results of this Workshop are described in Section 4. Following the Workshop, various actions by the APS staff led to the redesign of the front end components, which are presented in Sections 5 and 6. The cost benefit analysis is presented in Section 7.

It is important of realize that an added benefit of the Workshop was to obtain numerous design evaluations and enhancements of the front end components by experts in the field. As the design work proceeds to Title II completion, the APS staff is including many of these suggestions.

1. Introduction

Argonne National Laboratory is currently constructing the Advanced Photon Source (APS), which will be a premier National User Facility for x-ray research. In January 1990, the Value Engineering (VE) process was successfully applied to the conventional construction involved in the Advanced Photon Source Project. This leads to considerable savings in the cost of conventional construction without loss of functional goals of the project.

In the present case, the same approach has been applied to a set of technical components. As a part of the Experimental Facilities, about 16 insertion device beamlines and 16 bending magnet beamlines will be constructed. Each one of these beamlines consists of a front end, which confines, defines, and stops or delivers the intense x-ray beams produced for the users. Because there are many components in these beamline front ends that recur a large number of times, a fruitful VE process (described in Section 2 of this Report) can lead to considerable cost savings to the project.

The Value Engineering Workshop on APS Beamline Front Ends took place on November 5-6, 1992 (see Appendix A for the agenda). Technical experts in this area were invited to contribute. They were:

Dick DiGennaro (Chair)	Lawrence Berkeley Lab
Richard Boyce	SSRL
Rich Hewitt	Exxon Research
Hans Jostlein	Fermi Lab
Brian Newnam	Los Alamos National Lab
J. C. Schuchman	ANL-APS/ASD
S. Sharma	ANL-APS/ASD
E. Trakhtenberg	ANL-APS/XFD

In addition, all the members of the Engineering and Construction (EC) Group in the Experimental Facilities Division of the APS also participated in the workshop. This Group has the primary responsibility for design, construction, installation, and commissioning of the beamline front ends.

This report was compiled by the EC Group to document the outcome of the VE Workshop. The report contains information extracted from the November 1991 Title 1 Design Report on the beamline front ends. This material (see Section 3) was presented to the VE team and forms the baseline for cost comparison.

The information gathered from the creative and judgment phases of the VE process is also included for each of the subcomponents of the front end (see Section 4). The resulting new design of the front ends is presented in Section 5. Section 6 briefly addresses issues demanding further design work. Finally, from a preliminary design study performed by the EC Group on each of the VE Workshop creative ideas, a cost benefit study is included (in Section 7).

Although the primary purpose of the VE Workshop was to address VE issues, the participants have contributed in a major way toward enhancing the design of all the front end components.

2. Value Engineering Process

2.1 Introduction

Past experience from the Value Engineering (VE) Workshop on Conventional Facilities of the APS has shown that a well-developed procedure results in a successful workshop. It should be emphasized that VE is *not* intended to be a review of previous design effort. Hence, in this process, the VE team is viewed as a partner in accomplishing the goals of VE, namely to help generate ideas to reduce costs of technical components.

The conclusion of the workshop should lead to either newer design of the subcomponents or confirmation of the current design. At that time, a "bottoms-up" cost estimate is done to evaluate the gain from the VE process. In the following, the VE process as applicable to beamline front ends is described in detail.

2.2 The Process:

Value engineering is a systematic method of investigation to obtain the best functional balance between cost, reliability, and performance of technical components. During the actual workshop, the Job Plan involving the following Tasks will be followed. The Job Plan is an organized approach for searching out high cost and high multiplicity areas in the design and developing alternate solutions for consideration.

Tasks in the Job Plan:

A. Information Phase
B. Creative Phase
C. Judgment Phase
D. Development Phase
E. Recommendation Phase

These five tasks are described below:

<u>A. INFORMATION PHASE</u>

Background to Design:

At the beginning of the VE workshop, it is important to understand the background and decisions that have influenced the design. The APS/XFD staff has spent much time and effort in the analysis of design alternatives, performing engineering calculations, generating various possible layouts for the front ends, and other areas of design. During this phase, the XFD design team will present the current status on the design to the VE team. The VE team must become familiar with every aspect of the design so as to identify high cost areas. Being cognizant of the XFD designer's knowledge helps one understand the rationale used in the design work and develop only useful alternative concepts.

The XFD design team will provide Title 1 or more recent design documents to the VE team. In addition, at the beginning of the workshop, the design team will present oral descriptions of the functions and designs of various components of the front ends.

Design Costs:

The XFD design team will also provide cost estimates and backup data in the form of a document to the VE team. It will include costs at various WBS levels in the format prepared for the Title I document. If there are no changes since the Title I stage, the same costs should be included. This gives the VE team the opportunity to look at high cost areas that warrant special attention.

Function Analysis:

The functions of various components will be presented in detail by the XFD design team to the VE team, with special attention drawn to current APS safety philosophy that might have influenced the functional placement of the components. This is beneficial to the VE team because it forces the participants to provide ideas within the framework of safety requirements. Preparing the function analysis helps generate many of the ideas that eventually result in recommendations for cost savings. High multiplicity components in the design also receive special function analysis. This analysis also forces the VE team to explore alternate designs for such components that retain their functional capabilities.

B. CREATIVE PHASE

Every idea generated by the VE team during this phase should be written down during this part of the workshop. These ideas should be sorted by WBS categories.

During the creative phase, the VE team brainstorms by thinking of as many ways as possible to provide the necessary function (within the technical constraints) at a lesser cost. No judgment of the ideas should be carried out at this time. The screening of the ideas takes place in the next phase.

C. JUDGMENT PHASE

In this phase, the VE team judges each of the creative ideas generated in the previous phase. The ideas are ranked by the VE team on a scale of 1 to 10, with 10 being the highest rating. Discussion of each idea results in an evaluation of the advantages and disadvantages of each idea. These must be recorded during this phase. Ideas found to be irrelevant or not worthy of additional study are disregarded or given a low rating; those ideas that represent the greatest potential for cost savings are then developed further in the next phase. Ideally, the VE team would like to develop fully all the ideas, but time constraints usually limit the number.

D. DEVELOPMENT PHASE

During this phase, the VE team develops each of the higher rated ideas into a workable solution. This includes development of a preliminary design and a descriptive evaluation of the advantages and disadvantages of the proposed recommendations. Also, the VE team should estimate the costs to the best of their ability, although this exercise may be limited by a lack of detailed engineering.

It is important that the VE team be able to adequately convey the concept for their recommendation to the XFD design staff, because, if the proposal is not understood, it is not likely to be accepted. Hence, sketches, design calculations, and brief narratives should be provided.

E. RECOMMENDATION PHASE

The last phase of the VE workshop involves listing the recommendations along with the proposed cost savings and presentation of these results to the XFD design team and the APS management during the last session of the workshop.

In the summary portion of the workshop, the XFD design team will include an acceptance list of items from the VE recommendations. These ideas will be included in the final design of the front ends.

3. Front End Description

The front end of an insertion device (ID) beam is described by logically dividing the functional components into a Work Breakdown Structure (WBS). A complete listing of a WBS is given in Appendix B.

The Engineering and Construction Group (EC Group) of the Experimental Facilities Division (XFD) is responsible for the research and development, design, construction and installation of the beamline front ends for the APS. The description given in this section represents the design of the front ends prior to the VE Workshop.

3.1 Advanced Photon Source Storage Ring Layout

Traditional synchrotron sources were designed to produce bending magnet radiation and have proven to be an essential scientific tool. Currently, a new generation of synchrotron sources is being built that will be able to accomodate a large number of insertion device (ID) and high quality bending magnet (BM) sources. One example is the 7-GeV Advanced Photon Source (APS) now under construction at Argonne National Laboratory (ANL). The research and development effort at the APS is designed to fully develop the potential of this new generation of synchrotron sources.[1]

Of the 40 sectors in the APS Storage Ring, 34 will be available for IDs. The remaining 6 sectors are reserved for the Storage Ring hardware and diagnostics. Although the ring incorporates 80 BMs, only 40 of them can be used to extract radiation. The accelerator hardware shadows 5 of these 40 bending magnets, so the maximum number of BM sources on the lattice is 35.

3.2 Description of Beamline Front Ends

Generally, a photon beamline consists of 4 functional sections. The first section is the ID or the BM source, which provides the radiation. The second section, which is immediately outside the Storage Ring but inside a concrete shielding tunnel, is the front end (FE), which is designed to control, define, and/or confine the x-ray beam. In the case of the APS, the front ends are designed to *confine* the photon beam. The third section, just outside the concrete shielding tunnel and on the experimental floor, is the first optics enclosure (FOE), which contains optics to filter and monochromatize the photon beam. The fourth section of a beamline consists of beam transports, additional optics, and experiment stations to do the scientific investigations. This document describes only the front ends of the APS beamlines. An early conceptual study of the APS front end design is given in reference [2].

By 1996, the APS will complete 32 front ends, 16 ID sources composed largely of undulators and, to a lesser extent, wigglers and 16 BM sources. A detailed physics study of the APS sources is provided in reference [3]. Table 1, based on reference [3], provides useful beam characteristics data on the currently planned APS sources.

3.2.1 The APS Front End Design and Safety Philosophy

The APS front ends are standardized and modularized to achieve several purposes. As mentioned above, by 1996, 32 front ends will have been built. This is a large enough number to warrant standardization for the resulting reduction in cost. In addition, standardization results in reduced engineering and design effort, ease of manufacturing, quality control and quality assurance, ease in installation, and reliability in maintenance and operations. Because of the geometric properties of the radiation produced by either insertion devices or bending magnets, fundamental differences exist between the front ends for the ID beamlines and those for the BM beamlines. Thus, two kinds of APS front ends are being developed: one for the IDs (currently planned undulators and wigglers) and another for BMs. The ID front end components are designed for the most critical wiggler size and for the highest heat flux levels of the APS undulators to accommodate the variation in the radiation properties produced by wigglers and undulators. This approach results in a single design to suit all the APS ID front ends.

Needless to say, the standardized designs of the APS front ends also must satisfy the baseline requirements for any front end design. That is, the front ends are configured via a complex design, control, and interlock system:

(i) to ensure personnel safety with the required redundancy and logical control systems during commissioning and operating phases,

(ii) to maintain the ring vacuum integrity,

(iii) to provide proper collimation so that the beam cannot strike unprotected and elements that are not cooled within the vacuum envelope even under steering errors,

(iv) to provide shuttering and, hence, absorbance of the full power of the beam and/or bremsstrahlung during injection and/or in case of a vacuum failure,

(v) to provide required information on the angular and spatial position of the photon beam n a feedback fashion to the ring side in order to maintain a stable beam,

(vi) to operate within the phase-space parameters of the beam that the experimenters expect and for which they prepare their equipment.

Regarding safety, the most probable accident in a front end is a vacuum breach at the traditional window location. On sensing such a breach, the front end is designed with vacuum instrumentation that can determine the rate of the propagation and decide whether it is a fast breach and the beam must be dumped, or whether it is slow enough to safely shut down the front end instead. Beam dump is fast and occurs typically within 10 μs. Because the fastest acting element on the front end to be affected by the dump is the fast valve with 7 to 9 ms actuation time, the valve remains safe. If the vacuum leak is deemed slow enough, then beam dump is not necessary. In this case, the front end is safely shut down until the next maintenance time. In the slow shut down process, one or both of the photon shutters (PS1 and PS2, respectively) are actuated to intercept the beam. This action takes about one second. In return, the interlock system triggered by PS1 actuates closing of the two safety shutters and the fast and the slow valves. Both the safety shutters and the slow valve close in one second. Because the PS1 is down, there is no danger from the beam to the slow or the fast valves. It has been suggested that because the respective ID "jaws" are also opened with this action, photon-induced gas loads from PS1 are reduced due to the diminished power from the ID.

During a ring fill when positron injection occurs, bremsstrahlung radiation can occur in the front end. To absorb the bremsstrahlung radiation, the tungsten safety shutters are closed. Because the safety shutters cannot stop the beam radiation, they are interlocked to PS1 and PS2 for thermal protection. Any neutron generation downstream of the beam pipe in the front end is absorbed by adequate boroted polyethylene treatment in and around the ratchet wall penetration.

The current APS front end designs meet the specifications listed in Table 2 for the first phase of the project. In the second phase, the front end designs are expected to meet operating specifications at 300 mA ring current with full size 4.8-m Undulators.

3.2.2 Front End Aperture Sizing

The standard design of the ID front ends is understandably much more complex than the BM front end design, and the ID front end design will be primarily detailed here. The ID front ends must satisfy the power requirements of undulators (U2.3 and U3.3) coupled with the horizontal beam size of wigglers (see Table 1). For a 100 mA ring current at 7-GeV positron beam energy, planned wigglers (for a maximum K factor of 14) cover a photon energy range of 5 to 32.6 KeV. The source ID radiation fan width is taken to be ± 1.5 mrad (for the BM front ends, the source fan width is ± 3.0 mrad).

A ray-tracing study using the SHADOW code[4] is the starting point in the design for requisite aperturing needs and the component size determination of the front end elements. This results in an optical pass configuration for the front end. This is shown in Fig. 1 in a 3D depiction. In Figs. 2 and 3, the same information is shown in vertical and horizontal planes, respectively. In Tables 3 and 4, the aperture sizes are listed for all the components on the ID and the BM front ends. The straight sections on the Storage Ring can have either one or two undulator- and/or wiggler-type 2.4-m devices or a single 4.8-m ID. The vertical and horizontal beam confinements for the ID front ends are complicated because of the possibility of placing various length IDs on the straight section. The calculated maximum acceptance angles for the beam under missteering conditions are presented in Table 5. In these calculations, the origin of the wiggler beam divergence is assumed to be at the very beginning of the straight section, whereas for undulators, it is at the center of the ID.

The APS front ends are housed within the storage ring tunnel. The shielding tunnel walls are made of heavy concrete and fashioned as a "dog-leg" ratchet wall to provide the maximum aisle access to the front end inside the tunnel. The usable length of the front end area of the tunnel is about 7.5 meters for both the IDs and the BMs and is necessarily congested by the components, particularly in the ID case. For all front ends, the access to the tunnel is via a sliding door in the tunnel wall (ratchet wall door). The front end environment provides the following features:

- Air temperature: $23 \pm 1^{\circ}$C
- Cooling DI water temperature: $23 \pm 1^{\circ}$C
- Serviceable through a sliding ratchet wall door
- Structurally stable and vibration free
- Survey and alignment availability
- Radiation protection:
  Requirements of APS-LS-141, "Radiological Design Considerations: Review of the Radial Ratchet Wall Shielding," are satisfied
- All utility/control modules are placed outside the FE tunnel

3.2.3 Layout of the ID Front End Components

Figure 4 is the elevation view of the conceptual design of the standard ID front end at the APS. In this conceptual design, the components on the ID front end are (in the order of their appearance in Fig. 4):

1. All metal ring isolation valve
2. Photon beam position monitor 1
3. Fixed mask 1
4. Photon shutter 1
5. Collimator
6. All metal slow valve
7. All metal fast valve
8. Photon beam position monitor 2
9. Fixed mask 2
10. Photon shutter 2
11. Filter assembly
12. Integral safety shutter/collimator
13. Ratchet wall penetration
14. Window

In Figs. 5a through 5l, all the SHADOW ray-tracing plots are presented for the ID front-end components.

The above designs are nearly but not entirely the same as those that were critiqued by an independent Design Review Board (DRB), and which were subsequently costed and approved at the Title I review conducted by the U.S. DOE Engineering Research Committee in FY 1991.

The design challenge of the APS ID front ends lies in packaging all of the front end components in the tight space available. Both the maximum height and the maximum width of the components must be considered carefully to ensure the front end is serviceable during operation. Therefore, nothing should be mounted lower than at 2.2 meters elevation in the synchrotron tunnel, and a mere 515 ± 15 mm width is available between the front end edge plane and the ratchet wall to slide the components in and out of the tunnel. The width of the component support table had to be closely controlled to a maximum of 485 mm to make room for such movement. In the front end design, it is preferred that the components stay with their respective table supports during such maintenance and servicing. This greatly facilitates subsequent front end alignment problems. The total power, peak heat flux and the beam width of the planned IDs combined with the limited space available result in tough engineering challenges in the front end component designs. From Table 1, it is seen that the normal incidence heat fluxes from the planned IDs at the PS1 and PS2 positions are very large, typical values being on the order of 450 W/mm^2 or higher. Designing for such heat flux levels and/or for large total heat load (on the order of 10-15 kW) poses significant engineering and material challenges. The result has been what may be termed a "grazing-angle front-end design." This is the only way one can handle the associated thermal and material problems associated with the planned IDs even with the enhanced heat transfer method available at the APS.

The design of the APS ID front ends includes two fixed masks and two photon shutters. In addition to confining the beam, the fixed masks serve to limit the length of the photon shutters placed immediately downstream.

An overview is given below for the major components of the APS ID front end as well as the current state of the research activity associated with a particular component.

3.2.4 Overview and Design Description of ID Front End Components

APS insertion devices include both wigglers and undulators, and the properties of the radiation produced by these devices vary. However, if the ID front ends are designed for the most critical wiggler size and the highest heat flux levels of the undulators, a single design should be suitable for all APS ID front ends. Figure 1 shows the physical layout of an ID front end. The components of a typical ID front end are described below in the order of their placement from the ID source.

Exit Valve: This is an all-metal valve that is UHV vacuum tight. It isolates the front end from the Storage Ring. Opening this valve is strictly controlled administratively.

Photon Beam Position Monitor (PBPM): This device is a cooled multi-blade system, in horizontal and vertical disposition, placed in the fringes of the beam to detect the position of the beam. At the APS, there are two PBPMs, the second is placed approximately 3.6 m downstream of the first. Together they yield precise beam position information. When swept by the beam, the blades of the APS front end PBPMs generate photoelectrons. This, in turn, causes a microampere-level photocurrent in each blade that can be measured and reduced to correlate with the degree of deviation of the beam from its orbit. The beam missteering on the ring side is to be kept within ten percent in both position and divergence. When excessive deviations are detected, the output from the PBPMs is fed back into the ring correction (steering) magnets to adjust the beam's position and the angle at the ID center. In the extreme case of beam tracking loss, the PBPM can trigger a beam dump. PBPM signals are fed back to the ring for proper beam steering.

The APS machine side requires, with the two PBPMs spaced apart as described above, a precision of ±3.3 μm in the position and ±0.14 μrad in the angle of the particle beam. Given the power from the planned ID beams, early studies indicated that, with conventional blade materials, it would be very difficult to reliably meet these specifications. Therefore, we looked into new blade materials and introduced the use of metallized CVD diamond blades for the ID front ends . The APS PBPM prototypes with such blades were tested at NSLS on the X-13 beamline, at CHESS on the APS/CHESS short undulator front end, and finally, again, at NSLS on the X-25 focused wiggler beamline. These tests have proven beyond reasonable doubt that we can achieve submicron sensitivity (on the order of 0.2 μm) with CVD diamond blades under all conventional operation. The dynamic range of the current CVD diamond blades in synchrotron tests was shown to be at least 2 mm. The current design and the research activity associated with the APS PBPMs are presented in reference [5].

The latest tests at NSLS on X-25 proved that our CVD diamond blades can be heated to over 1000˚ C under very adverse conditions with no loss of integrity or performance. However, the PBPM blades have been designed not to exceed 600˚ C under full beam missteering when the beam from a 5-m undulator is allowed to directly impinge on the blade.[6]

The PBPM stage assembly consists of vertical, horizontal, and rotational stages. Because the commercially available vertical stages could not meet our specifications, we developed an in-house stage assembly. This stage assembly has been subjected to tests both in-house and also at the NSLS X-25 beamline. These tests prove that the vertical stage is reliable and can attain a stepping resolution of < ± 0.2 μm.

Finally, the present PBPM head assembly design is shown schematically in Fig. 6. The first PBPM has six CVD diamond blades, four placed vertically in pairs and two single blades placed horizontally. The downstream PBPM also has six blades, however, now the vertical blades are placed singly, and the horizontals ones are in pairs. This configuration eliminates the blade shadowing problems. Undulator and wiggler PBPMs have fixed but different horizontal blade settings. If desired, the horizontal blades can be made movable to accommodate various IDs (undulators, wigglers, undulator wigglers) via a stainless ribbon drive on the horizontal jaws of the PBPM. A pull on the ribbon acts against two springs under compression resulting in precise position adjustment. This design is under study. For the bending magnet front ends, the PBPM is much simpler, consisting of only two vertical blades.

Fixed Mask Assembly (Fixed Aperture): This is the first front end component to interact with the beam. The fixed mask (FM) may be exposed to the full beam or part of the beam and thus requires a careful design analysis. A similar mask is located further downstream on the front end. In the case of the APS, both assemblies are designed to contain the beam but not define it. Despite this, these assemblies are designed to absorb the full beam of any IDs planned for the first phase at the APS. An extensive heat transfer research and development program has been undertaken at the APS to find a generic but efficient tube configuration for enhanced cooling of the large heat loads that may be imposed on both the fixed and the movable mask walls. This will be detailed further in a later section.

The engineering drawing for the fixed masks is presented in Fig. 7. Both masks are electric discharge machined (EDMed) from a solid bar of OFHC copper to provide a central aperture as specified in Table 3. The sides of the aperture form a 3-degree included angle between both the horizontal and the vertical walls. Analysis proves that the horizontal walls are subject to the worse thermal loading. Therefore, the horizontal aperture walls are brazed with a thin (3 mm) Glidcop faceplate to offer a higher yield strength and better thermal fatigue resistance for the first phase ID front ends.

Cooling is affected outside the UHV envelope by water in channels machined right into the aperture walls. The channels are subsequently filled with a porous copper matrix for higher convective heat transfer. The matrix is brazed to the aperture walls for good thermal contact. The end walls of the aperture body are machined to be subsequently welded to the stainless steel UHV flanges.

Photon Shutter (Movable Mask): This component completely intercepts the x-ray photon beam via a fast-acting mechanism in order to isolate the downstream components from the source. Closing time may be as long as a few seconds (NSLS) or as short as 55 ms (ESRF). In our current design, we are using a slow actuator with a closing time of about one second. For future use, a fast closing option (50 ms) is under research and development. The photon shutter also acts as a safety device to protect the safety shutter from direct beam impingement. Therefore, the photon shutter is interlocked to close before the closing of the safety shutters (two of which are required as per the APS Preliminary Safety Analysis Report, PSAR). The positions of both the photon shutter and the safety shutters are redundantly indicated. That is, the photon shutter must be first closed and last opened and has redundant closed-position indication (fail-safe). The position of the safety shutter is redundantly indicated in both up (open) and down (closed) positions.

Figures 8 and 9, respectively, show the first and the second photon shutter assembly drawings. Both shutters have the same configuration employing a "hockey stick" shaped copper absorber blade. The first photon shutter serves as the traditional shutter in the front end and is interlocked to the front end vacuum system. As such, it is acted upon during injection and during vacuum-triggered shut-down events. This reduces the actuation frequency for the first photon shutter very significantly mitigating the common bellows-type failure in such devices. The second photon shutter is used exclusively by the experimenters and, as such, is very frequently actuated. The hockey stick absorber blade is hinged from both ends (Figs. 8 and 9), and the complete assembly can be removed intact from the flanged side for replacement or maintenance. The first photon shutter blade is set to the beam at a 1.5 degree grazing angle, and the second one is at a 2 degree grazing angle. The photon shutters offer common features such as:

- Common tube design
- UHV containment
- Cooled containment against reflected/scattered radiation
- Fail-safe design
- Replaceable absorber tube
- Initial alignment viewing ports

The absorber tube is hinged from the flange end using no-slack flexural couplings. Likewise, from the actuator side it is connected with a flexural coupling.

At the APS, the fixed mask and the photon shutters use a common and generic coolant tube with enhanced heat transfer capabilities.[7,8] The tube is filled with a copper foam (copper wool) brazed to the inside walls of the tube for good thermal contact. In addition to causing highly enhanced heat transfer, the presence of the copper wool (porous filler) in the flow tube provides other benefits. At the expense of an increased pressure drop, the porous matrix in the tube makes them very quiet, nearly jitter free. This is an important consideration for critical components such as PBPMs, masks, and, potentially, slits and first optics crystals where flow-induced jitter can become a serious concern. Additionally, these tubes require a relatively small amount of flow to achieve high convective heat transfer coefficients, an important consideration from an operational point of view. Thus far in laboratory studies, we have achieved enhanced heat transfer coefficients (h > 4 W/cm^{2}K) in such tubes using a variety of meshes. Our design goal is to obtain an h value of 3 W/cm^{2}K with about 2.5-3.0 psi in pressure drop. The APS ID front ends have many components requiring very robust cooling due to the high heat loads imposed on them from very powerful IDs. Conventional techniques for cooling would have resulted in an order of magnitude higher flow requirements in the front end. Research is continuing at the APS to optimize the tube geometry and the porosity.

A great deal of analysis has been conducted on the thermal, structural, and the vibrational problems of both photon shutters. These are included in references [9, 10, 11, 12]. The analyses seem to prove that the most critical component of the front end, the first photon shutter (PS1) as designed will satisfy the stringent thermal, structural, and vibrational requirements during operation with the 2.4-m Undulator A of the APS (which will be the initial source). The technical requirements for the future 4.8-m Undulator A, including a design safety factor, are very challenging, and the research and development effort is continuing into an engineering solution for the thermal problems of the photon shutter and the fixed mask.

Collimators: These components are required to define the line of sight to the source point and to allow a cone of the beam to pass through. Portions of the beam outside the predefined cone and any other scattered x-rays, as well as the bremsstrahlung, are absorbed by the collimator body. The APS front-end collimators are at least 30 cm (12 in.) lead equivalent in length as per the PSAR.

Slow Valve: This is an all-metal remotely actuated UHV valve that seals to isolate the ring from any vacuum breach in the downstream transport piping. The closing time of this valve is usually 1-2 seconds. However, it cannot accept the heat load from the photon beam and therefore has to be interlocked to close only when beam is NOT present or the photon shutter is closed. Closing of the slow valve occurs after the closing of the fast valve (below), which helps to retard the vacuum conductance upstream in case of a vacuum breach.

Fast Valve: The fast valve is positioned immediately downstream of the slow valve. The modern all-metal-seal fast valves close in as little as 5 to 9 ms, thereby retarding the vacuum progression upstream. This valve, however, does not seal and cannot support even instantaneous exposure to a full photon beam without physical damage. Therefore, it is interlocked to the photon shutter during operation. On vacuum failure, the photon shutter is activated, which triggers immediate beam dump. Once the photon shutter is down, the fast valve closes, followed by the closing of the slow valve. In our laboratory tests, a V.A.T fast valve has been cycled more than 100 times with less than 7 ms closing time.

Filters: The front-end filters, if and when used, are designed to protect the window thermally and structurally. Filters are typically pyrolitic graphite foils and absorb and dissipate heat from unwanted portions of the photon beam spectra. They are radiatively and/or conductively cooled. Cooling is provided by passing water around the filter frame directly or through the filter holder box walls in an indirect fashion. While provision has been made to install such filters in the ID front ends, research proves that it is virtually impossible to reliably design filters and windows for certain undulator-type IDs that can meet the photon flux and/or photon energy requirements of the users. In such cases, a filter box will be removed for windowless operation of the front end. A differential pump replaces the window in these cases, which may constitute a majority of the APS ID front-end designs, and will be explained further in the following.

Safety Shutters: These shutters (two independently but simultaneously operated shutters are required per front end per APS PSAR) absorb bremsstrahlung radiation from scattering of the particle beam during injection of the beam into the Storage Ring. Therefore during each injection mode (maybe every 8-10 hrs. of operations), these shutters are closed (down). Conventional material for the safety shutter is a block of lead or tungsten. This shutter is usually not cooled, but does absorb all the bremsstrahlung radiation coming through the line. Because it is not cooled, it should not be exposed to the photon beam. Therefore, the upstream photon shutter 2 is interlocked and sequenced to close (down) before the safety shutter is closed (down).

In conventional designs, such shutters are designed as "dumb" blocks. When they are lowered for bremsstrahlung shielding, they completely block the possible line of sight of the radiation cone from upstream as seen from downstream. In our design, we have contrived a "smart" shutter by combining the "shuttering" with a "collimation" function.[13] The result is our "integral shutter/collimator," which is shown in Fig. 10. The shutter block, made of special UHV-compatible tungsten, consists of two parts. The smaller upper part (about 40 lbs.) is raised and lowered into the fixed and heavy lower part (about 200 lbs.) to provide collimation in the raised position and complete shuttering in the lowered position. The overall dimensions are 200 mm wide, 120 mm high, and 300 mm long. The adequacy of the heavy metal length has been reaffirmed by a recent study on the radiation shielding.[14]

The current design has resulted in:

- compactness, saving axial space
- a light duty actuator
- faster shuttering
- small stroke in actuation
- increased reliability of the UHV bellows
- much improved collimation in the front end
- conductiveness for future "top-off mode" operation

Window: The window is a vacuum separator and is positioned as needed between different vacuum transports and/or experimental stations. The front-end window is located at the end of the front end transport and separates the ring vacuum (front end vacuum) from the experimental beamline vacuum. For easy maintenance and access, the window is located outside the synchrotron tunnel on the First Optics Enclosure (FOE) side and is separated from the front end via a UHV valve. The APS window is a dual diaphragm assembly with a tag gas in between. Dual window diaphragms lend added assurance for two reasons. The second window on the downstream side does not absorb much heat because most of the absorbable soft x-ray photons are absorbed by the first window. As such, the second window remains structurally strong to absorb atmospheric shock. Also, should one of the window diaphragms fail, the other one can assure vacuum integrity until the failed window is replaced. The traditional window material is beryllium, although the high heat loads expected from APS undulators may force us to seek alternate window materials such as diamond-coated beryllium or CVD-diamond wafers. These windows as well as the upstream filter assembly are currently under research and development at the APS.[15]

The tag gas is traditionally helium, although other gases may also be considered. The purpose of the gas is to keep the wafer surfaces free from oxidation/carbonization and to indicate when a vacuum breach occurs. The gas space is interlocked for beam stoppage/dumping when a vacuum breach is sensed by the gas system. Design of the filters and the windows in APS front ends is a very important issue and the subject of considerable current research building on earlier studies [16 and 17].

As a matter of philosophy, the APS believes that the beam filtering in the front end should be the minimum required to maintain the structural integrity of the window and, thereby, assure the requisite vacuum safety in the front end. The filter assembly is designed so that only the unwanted portions of the beam energy are absorbed; thus, the window is thermally (hence, structurally) protected. Otherwise, a user-selectable filter box is located on the beamline to satisfy different optical requirements by the experimenter.

It should be noted that the APS ID front ends are not designed to have vacuum delay tanks (BM front ends do have vacuum delay tanks for particular reasons). The engineered and intrinsic ample aperturing in the ID front end is expected to provide good vacuum delay. The present vacuum analyses indicate that, with the excessive distributed aperturing and the front end length (approximately 24 m for ID lines and 22 m for BM lines), the APS ID front ends afford intrinsic vacuum delay. This will be verified in laboratory tests.

3.2.5 Bending Magnet Front Ends

In Fig. 11, the conceptual design of the APS BM front-end plan and the elevation views are shown. The BM front-end components, in order of their appearance in Fig. 11, are:

1. All metal exit valve
2. Fixed mask 1
3. Photon beam position monitor 1
4. Fixed mask 2
5. Photon shutter 1
6. Slow valve
7. Fast valve
8. Vacuum delay tank
9. Photon beam position monitor 2
10. Fixed mask 3
11. Photon shutter 2
12. Safety shutters
13. Ratchet wall penetration
14. Be window

Although the operational philosophy of the BM front end is the same as that for the ID front end, the power and the power densities that are handled by various components in BM front end are significantly smaller. Hence, the engineering of the BM components is less challenging. A brief description of the component assemblies is provided here.

The bending magnet front end starts with an all-metal mechanical exit valve. The vacuum transport behind the shield wall is a 6" stainless steel pipe to accommodate the ± 3-mrad wide x-ray fan from the APS bending dipoles. Beyond the shield wall, the vacuum transport becomes 8" to handle the widened x-ray fan. The exit valve is followed by a small 120 l/s vacuum pump to assure good vacuum by the ring exit, and the first of the two photon beam position monitors (PBPMs) is placed right after the vacuum pump with its own small pump. A second PBPM is found on the beam transport about 4.0 m away. These two PBPMs provide vertical beam position, as well as beam slope information, to the experimenters and the Storage Ring feedback system. The PBPMs are bellowed and mounted on specially designed stands for motor controlled adjustment.

A fixed mask assembly (FMA) is placed downstream of the first PBPM and before the photon shutter to confine the beam and protect the downstream components. The mask opening along with other apertures are provided in Table 3. The photon shutter is of conventional design with a cooled copper block that is pneumatically actuated. A collimator and the slow and fast vacuum valves follow the photon shutter.

A double safety shutter is the last element on the front end behind the shield wall. The safety shutters are the same design as the ID front-end safety shutters. Their up (open) and down (closed) positions are redundantly indicated. The safety shutters, the photon shutters, and the fast and the slow valves are interlocked in the conventional manner.

The large unoccupied vacuum transport between the valves and the safety shutter has only one 120 l/s vacuum pump mounted on it. This spool piece has been fashioned in the form of a vacuum delay tank. Such a vacuum delay tank is expected to be useful for the BM front end in the case of potential vacuum breaches because the larger size (6") and relatively simple BM front end transport does not offer an intrinsic vacuum delay as does the ID front end.

The BM front end fixed masks and photon shutters are made of OFHC copper and are ruggedly designed. Extensive analyses followed by prototype tests of the photon shutter using a high power CO_2 laser prove that the photon shutter can withstand large thermal loads and heat fluxes far exceeding even future operational requirements at the 300 mA current of the ring.

A pneumatically actuated double safety shutter is the last component on the front end behind the shield wall. The safety shutters are almost the same design as the ID front end safety shutters except the BM safety shutters have larger apertures to accommodate the ±3 mrad horizontal radiation fan. Unlike the ID front ends, all BM front ends are equipped with double Be windows. Windows are placed in the first optics enclosure (FOE) behind an 8" O-ring valve that is used for maintenance purposes.

3.2.6 The Front-End Vacuum

The APS front-end vacuum is designed to be a UHV system that is in the same range as the ring vacuum (10^{-11} Torr). Therefore, ultimate care is taken to maintain vacuum integrity and quality in the front end so as not to jeopardize the ring vacuum. In the space available, a 170 1/s ion pump is placed immediately after the exit valve to make sure that the ring side of the front end does maintain ring quality vacuum. On the FOE side, the front-end vacuum is separated from the beamline vacuum via a double window in all BM front ends. On the ID front ends, the same is true whenever possible. Otherwise, a differential pump replaces the window in the ID front ends. Thus far at the APS, we have designed and experimented with two different differential pumps. A differential pump made of three in-line 220 l/s ion pumps with large apertures for undulator/wiggler operation has demonstrated nearly a five decade difference. A second design employing two 220 l/s in-line pumps with a variable (10 to 14 mm) vertical and a78-mm horizontal aperturing has demonstrated nearly a three decade difference in simulated downstream gas loading with excellent time delays over 100 ms. Thus, it is clear that our differential pumps will be able to function very well. Research and development is underway to make sure that, with the differential pump operation, the vacuum safety in the front end and hence in the ring is not compromised even under vacuum venting in beamlines. In the months ahead, the requisite vacuum sensing and interlock systems to be used with the differential pump operation will be completely tested until we are convinced that the APS front ends can operate safely in a windowless configuration. This would give the experimenters full use of the most brilliant and powerful ID beams.

A strict rule applies to all synchrotron vacuum systems: there can be no water/vacuum joints in the beam transport, and all such joints and connections are isolated from the UHV by venting directly to the atmosphere. The direct link between the front end and the ring also dictates an additional engineering rule: the front end vacuum components should be durable, require little maintenance, and be highly reliable. Therefore, complex and unproved engineering practices are shunned. Materials are carefully chosen to function in a UHV environment.

The APS ID front-end vacuum pumping calculations show good pump-down characteristics. Adequate ion pumps standardized at the 220 l/s size supplemented with removable TSPs pumps have been provided in all front ends.

3.2.7 Power Load Limits and Design Requirements

This section provides a general overview of total power (Watts) and power density (Watts per unit solid angle) of various APS sources and the incident heat flux (Watts per unit area) on different front end components. It also examines their significance in the thermal and structural aspects of the front-end component design.

A major challenge in the engineering of the front-end components for high power ID-based synchrotron radiation facilities is the ability to keep the thermally induced stresses and deformations in the component materials within the accepted safety limits. While the total power imposed by the x-ray beam on a given component is of serious consequence, it is often the peak power density associated with the beam's profile that sets up thermal gradients in the material causing excessive thermal stresses and deformations. Table 1 lists the total power, peak power density, and the resulting heat fluxes on the critical front-end component for the planned sources of the APS in the first phase. In this phase, the stored positron current is 100 mA, and most of the insertion devices are 2.4 meters long with the exception of UW_{II} and Wiggler A_{III}, which are each 4.8 meters long. An examination of the sources in Table 1 shows that UW_{I} and Wiggler A_{III} are the most challenging IDs with respect to their front end designs. These devices combine very high peak fluxes with very large total power. For example, at the location of the first photon shutter (PS1), the peak heat fluxes at normal incidence are 456 W/mm^2 and 255 W/mm^2 with total power of 9.67 kW and 14.89 kW, respectively for UW_I and Wiggler A_{III}. Such heat fluxes are unprecedented and even exceed those encountered in rocket nozzles or in fusion reactors. The tools available to the design engineers and analysts to handle such large heat loads are a combination of the following: designing the heat load out by altering the geometry (use of grazing angles), use of the most effective cooling techniques (enhancement of the convective heat transfer coefficient in single phase heat transfer), and the use of structurally strong heat sink materials (Glidcop, Be, diamond, unisotropic carbon materials, cubic boron nitrates, etc.).

Fortunately, the front end components that are directly exposed to the x-ray beam, such as the fixed masks and photon shutters, can be designed to intercept the beam at grazing angles (1.5 to 3 degrees). Likewise, the beam position monitor blade edges can be set to the beam at shallow angles (10 to 20 degrees). The APS front end fixed masks and the photon shutters are designed to receive 15-20 W/mm^2 peak heat flux levels on their surfaces. In addition, employing a highly enhanced heat transfer technique developed at the APS (brazed porous copper mesh in cooling channels) with single phase water cooling, the maximum surface temperatures are kept at <200° C. The enhanced convective heat transfer coefficient attained is usually 3 W/cm^2 K or higher at modest water flow rates (the flow velocity is usually in the 1-1.5 m/s range). Even under these favorable conditions, the resulting thermal gradients in the fixed masks and the photon shutters give rise to appreciable thermal stresses, which are usually over 240 MPa and should be compared with the published yield strength of 400 MPa for special high strength copper such as Glidcop. More powerful x-ray beams (generated, for example, by higher ring energy or particle beam current) will necessitate additional ingenuity in solving the thermo-mechanical problems of fixed masks and photon shutters. The heat flux and the linear power density (which is found by dividing the total power by the horizontal extent of the beam) of the APS sources are known to be 4-5 fold higher than those of any contemporary synchrotron sources including the ESRF. The linear power density is the more meaningful measure of the resulting severity of the thermal stresses in components such as filters and windows, which are conduction limited. The linear power density from the APS undulators (at closed gap) is about three times higher than that for any other synchrotron source.

In summary, it seems fair to say that the heat flux and power levels generated by APS IDs are the highest that can currently be managed, and substantial changes both in concept and design will be necessary to accommodate more powerful sources.

3.2.8 References

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Table 1. Design Parameters of Various APS Insertion Devices for 7 GeV Ring Energy and 100 mA Stored Current

	Undulators				Wigglers		
	U2.8	U3.3	UWI	UWII	A_I	A_{II}	A_{III}
Period length [cm]	2.8	3.3	5.5	16	15	15	15
Device length [m]	2.41	2.4	2.4	4.8	1.5	2.4	4.8
Number of periods	86	72	44	30	10	16	32
Max. magnetic field B_o [T]	0.382	0.704	1.14	0.315	1.0	1.0	1.0
Characteristic energy E_c [keV]	12.45	22.94	37.15	10.26	32.59	32.59	32.59
$1/\gamma$ [mrad]	0.073	0.073	0.073	0.073	0.073	0.073	0.073
Max. deflection parameter K	1.0	2.17	5.86	4.7	14	14	14
K/γ [mrad]	0.073	0.158	0.428	0.343	1.02	1.02	1.02
Total power [kW]	1.09	3.69	9.67	1.48	4.65	7.44	14.89
Peak power [kW/mrad^2]	80.97	131.92	129.38	24.69	26.04	41.67	83.39
Peak power @ PS1 [W/mm^2]	285	465	456	75	67	111	255
Peak power @ PS2 [W/mm^2]	199	325	318	53	49	81	182
Peak power @ Win [W/mm^2]	144	235	231	40	37	61	134

Table 2. Global Specifications for the APS Front Ends

- 7 GeV Positron Beam Energy
- 100 mA Beam Current
- ID Radiation Fan = ± 1.5 mrad
- BM Radiation Fan = ± 3.0 mrad
- PBPM Sensitivity < ± 1 μm
- Beam Stability
    - Spatial Size ≤ ± 0.1 σ
    - Angular Size ≤ ± 0.1 σ'

Table 3. Optical Path Design and Analysis from Ray Tracing
in the APS ID Front End

Component	Location from Beginning of WA m	Physical Aperture mm x mm		2.044 x 0.292 Beam Size mm x mm
BPM 1	18.755	70 x 26		38 x 5.5
Fixed Mask 1	19.455	64 x 26	(in)	40 x 5.7
	19.755	52 x 14	(exit)	40 x 5.8
Photon Shutter 1	20.532	70 x 16		42 x 6.0
First Collimator	21.292	62 x 20	(68 x 26)	44 x 6.2
Fast Valve	21.946	70 x 18		45 x 6.4
BPM 2	22.365	70 x 18		46 x 6.5
Fixed Mask 2	22.745	70 x 18	(in)	46 x 6.6
	23.049	62 x 6	(exit)	47 x 6.7
Photon Shutter 2	23.848	70 x 10		49 x 6.2
Filters	24.675	72 x 10		50 x 6.5
Safety Shutter	25.764	72 x 10		53 x 6.8
Lead Collimator	26.837	72 x 20	(78 x 26)	55 x 7.1
Window	27.369	72 x 8.8	(w)	56 x 7.3
		72 x 12	(c)	56 x 7.3

Table 4. Optical Path Design and Analysis from Ray Tracing in the APS BM Front End

Component	Location from Beginning of WA m	Physical Aperture mm x mm		6.0 x 0.292 Beam Size mm x mm
BPM 1	12.725	102 x 24		76 x 3.7
Fixed Mask 1	13.665	110 x 50	(in)	82 x 3.99
		82 x 12	(exit)	
Photon Shutter 1	13.934	130 x 24		84 x 4.1
Lead Collimator 1	14.469	92 x 20	(26 x 98)	87 x 4.2
Fast Valve	15.299	110 x 18		92 x 4.5
Delay Line	17.316	125 x 30		104 x 5.1
BPM 2	18.02	125 x 18		108 x 5.3
Fixed Mask 2	18.510	125 x 20	(in)	111 x 5.4
		111 x 5.2	(exit)	
Photon Shutter 2	18.774	130 x 24		113 x 5.3
Lead Collimator 2	19.309	122 x 20	(128 x 26)	116 x 5.6
Safety Shutter	20.238	132 x 20		121 x 5.9
Lead Collimator 3	21.349	139 x 20	(145 x 26)	128 x 6.2
Window	21.868	145 x 8.8	(w)	131 x 6.6
		145 x 12	(c)	131 x 6.6

Table 5. The Beam Missteering Allowance

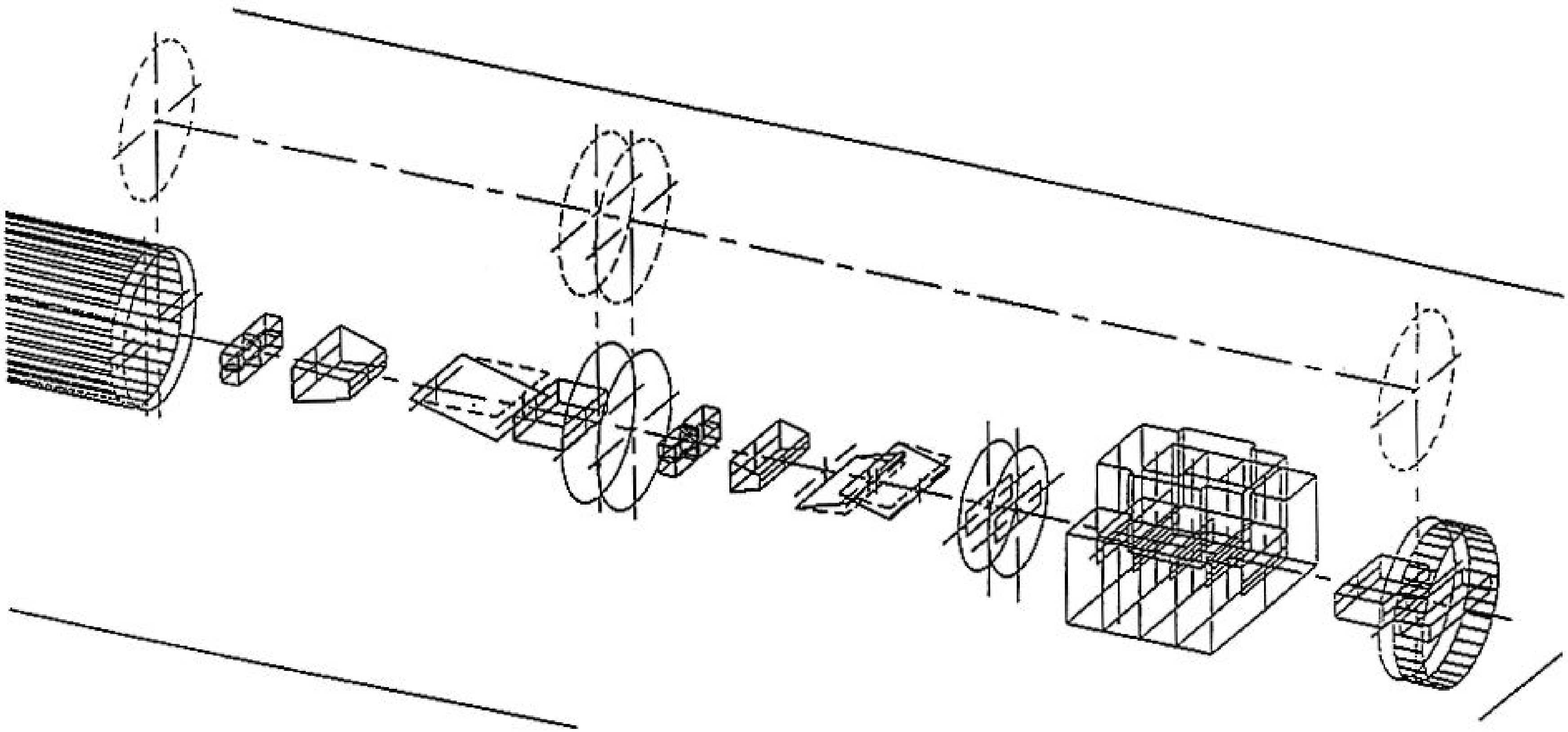
2.4-m Devices:

Max. Verticle Beam Missteering Acceptance	± 0.68	mrad
Design Vertical Pass-Through	± 0.28	mrad
Max. Horizontal Beam Missteering Acceptance (Undulators)	± 0.73	mrad
Max. Horizontal Pass-Through (Wigglers)	± 1.74	mrad

4.8-m Devices:

Max. Verticle Beam Missteering Acceptance	± 0.73	mrad
Design Vertical Pass-Through	± 0.28	mrad
Max. Horizontal Beam Missteering Acceptance (Undulators)	± 0.73	mrad
Max. Horizontal Pass-Through (Wigglers)	± 1.87	mrad

Figure 1. 3-D optical path schematic for the ID front end



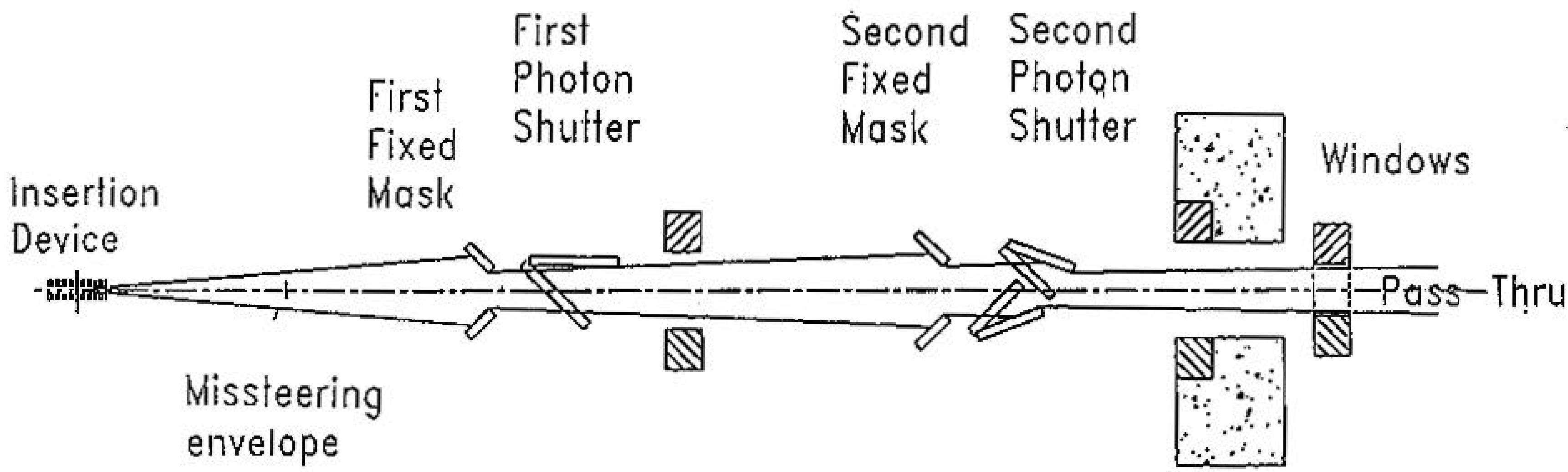


Figure 2. Vertical Beam Confinement in the ID Front End

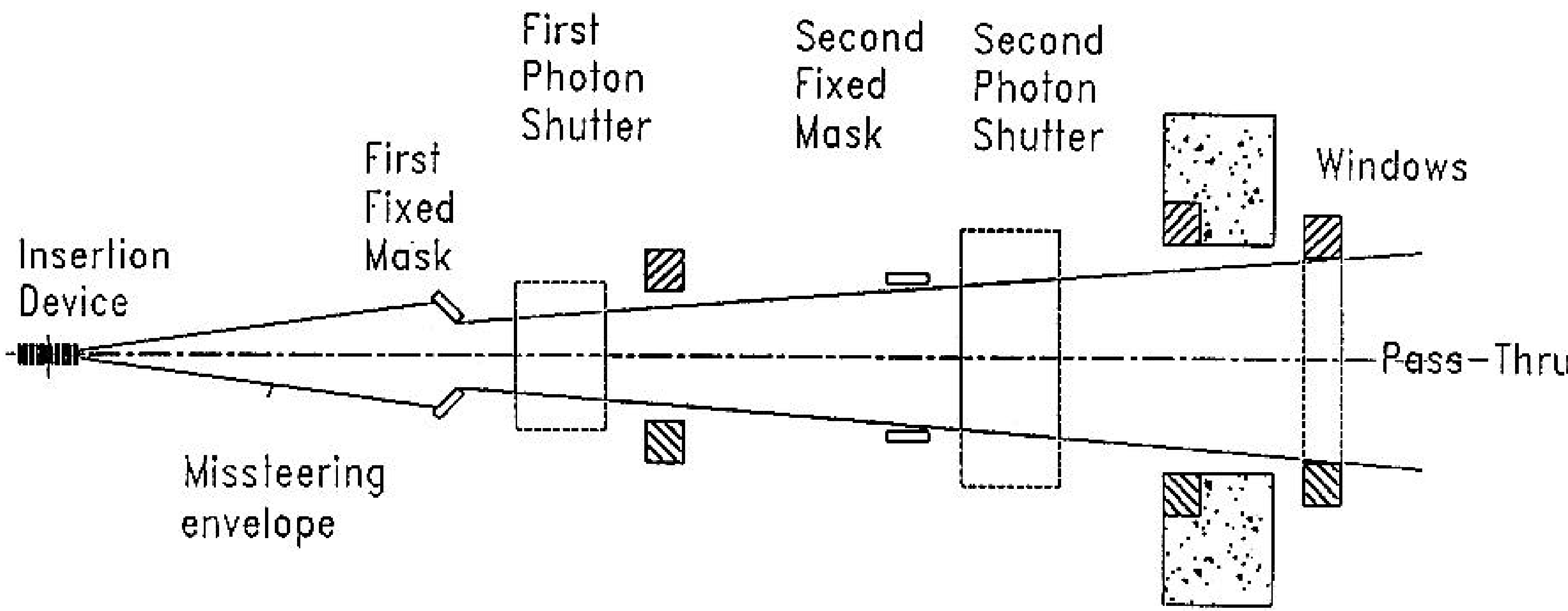


Figure 3. Horizontal Beam Confinement in the ID Front End

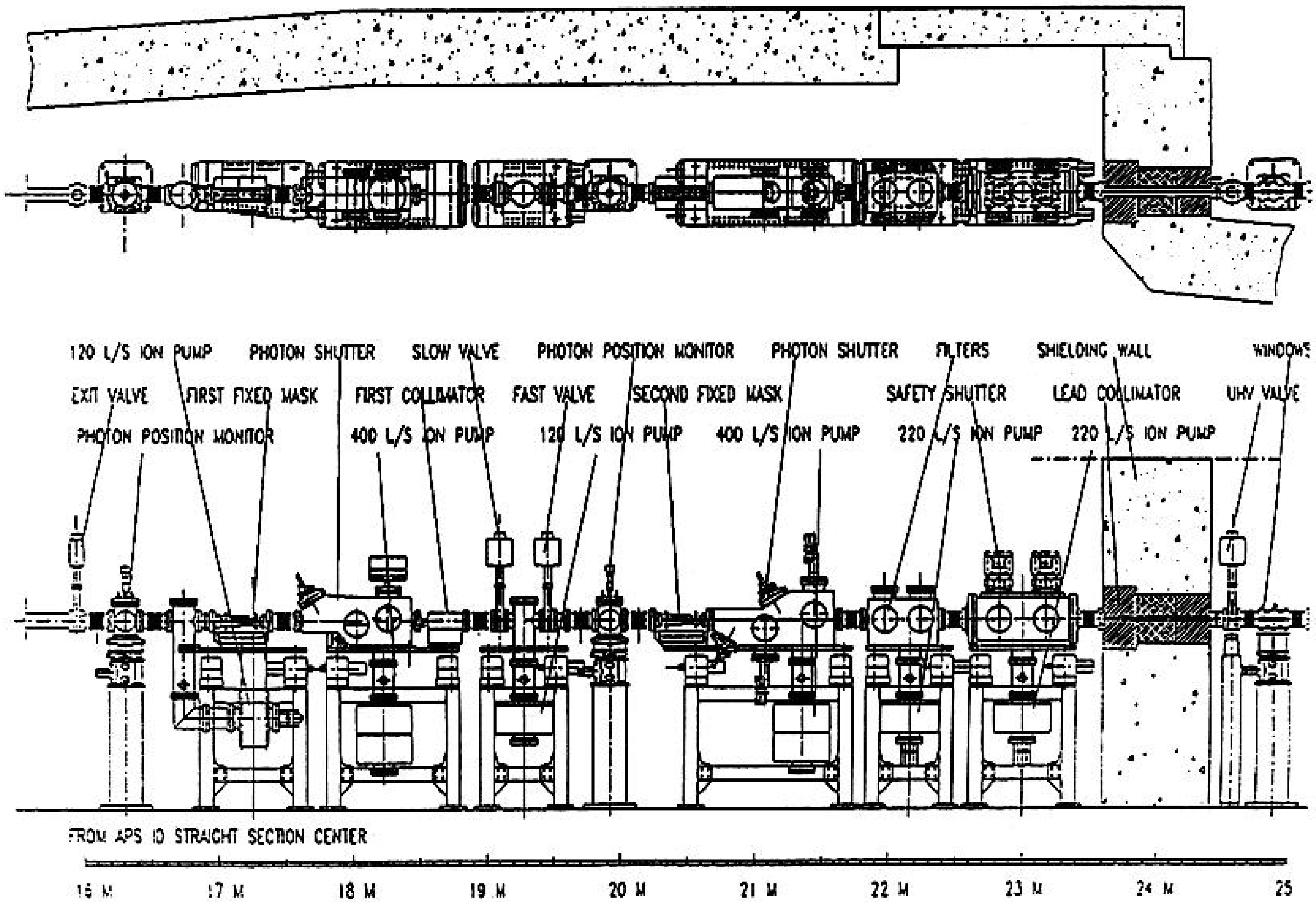


Figure 4. The APS insertion device front end layout

IDF4A.DWG 10-28-1992

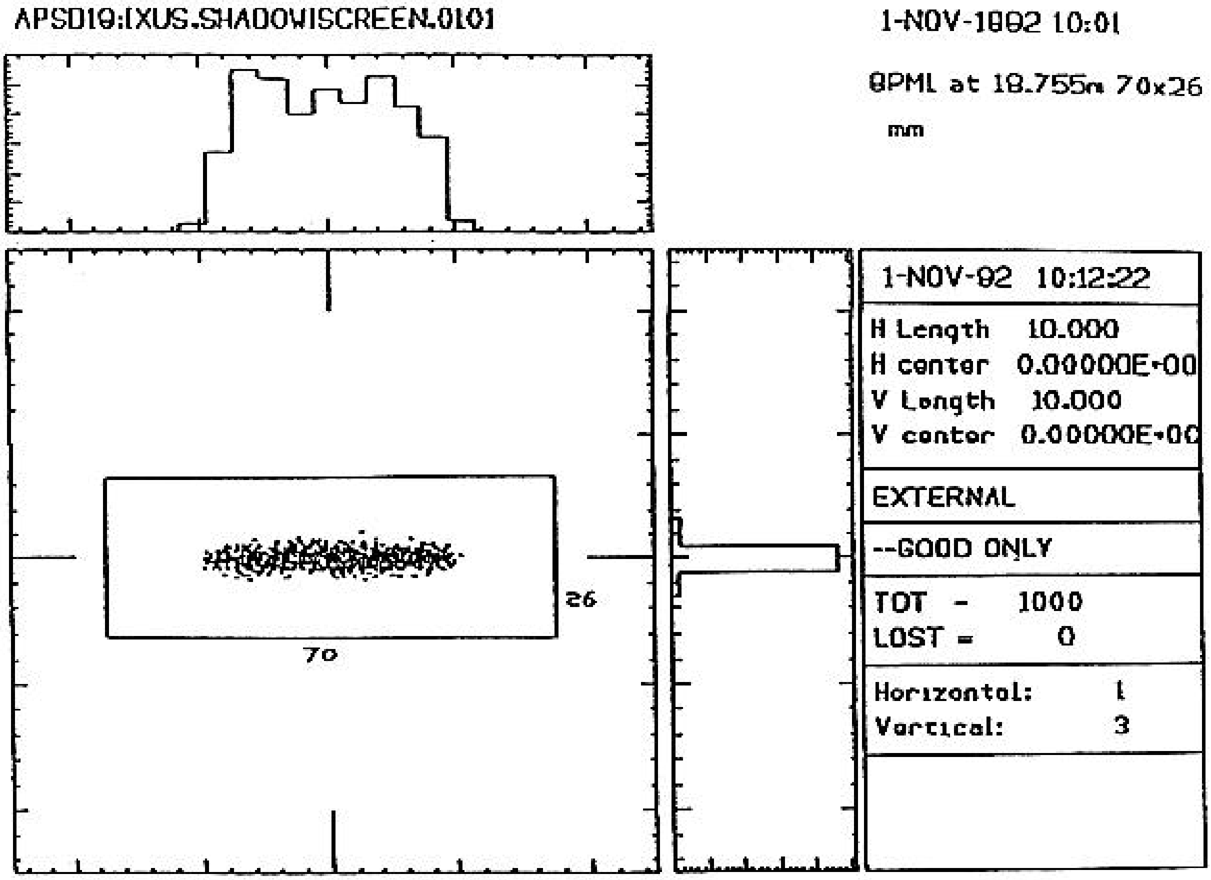


Figure 5a. SHADOW ray tracing for BPM1 of the ID front end

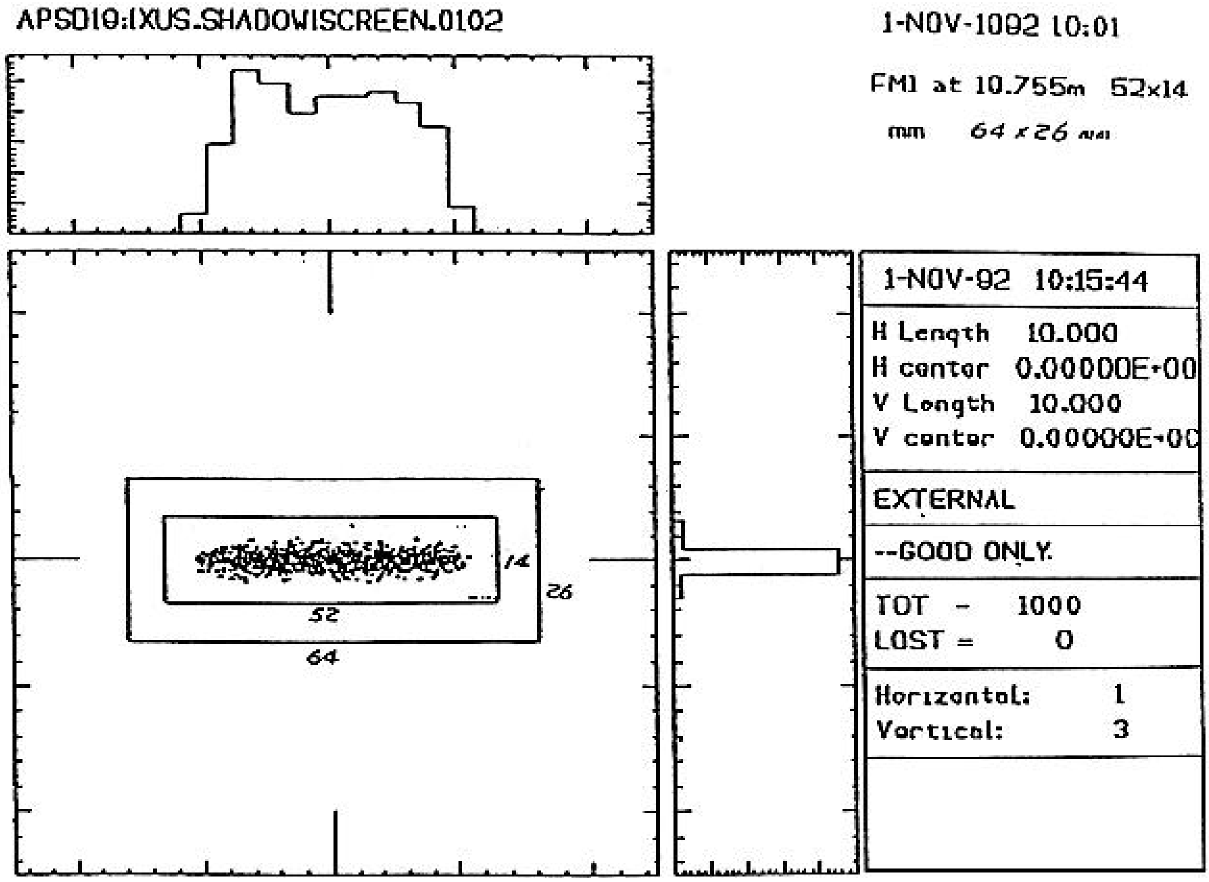


Figure 5b. SHADOW ray tracing for FM1 of the ID front end

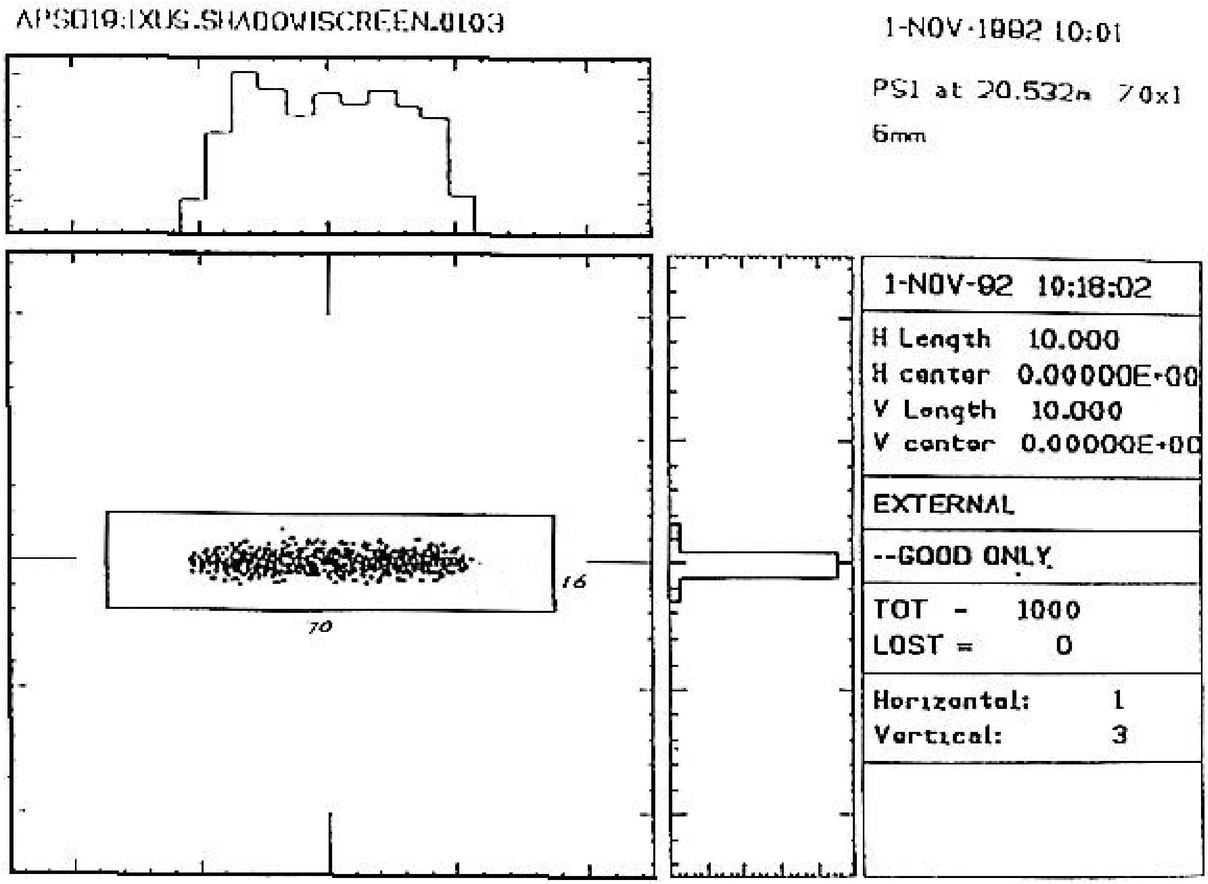


Figure 5c. SHADOW ray tracing for PS1 of the ID front end

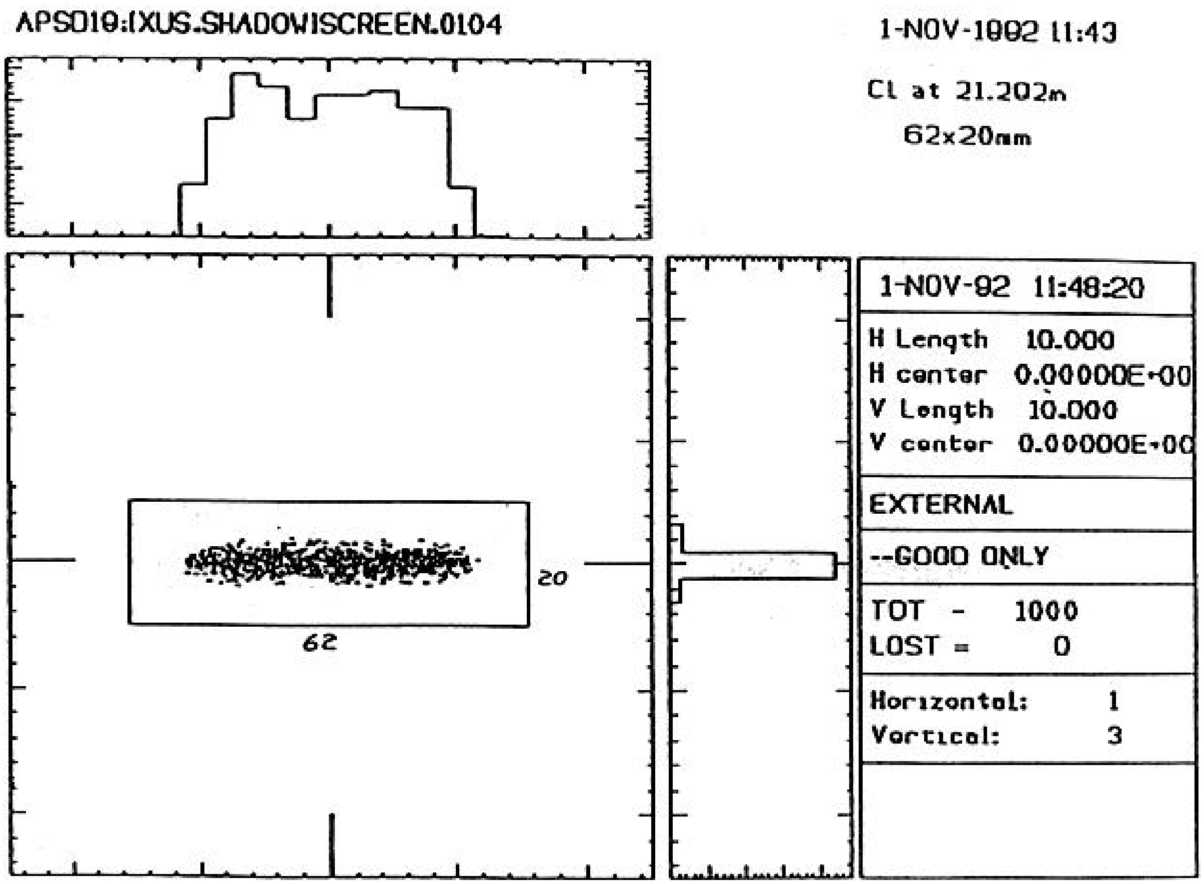


Figure 5d. SHADOW ray tracing for Collimator 1 of the ID front end

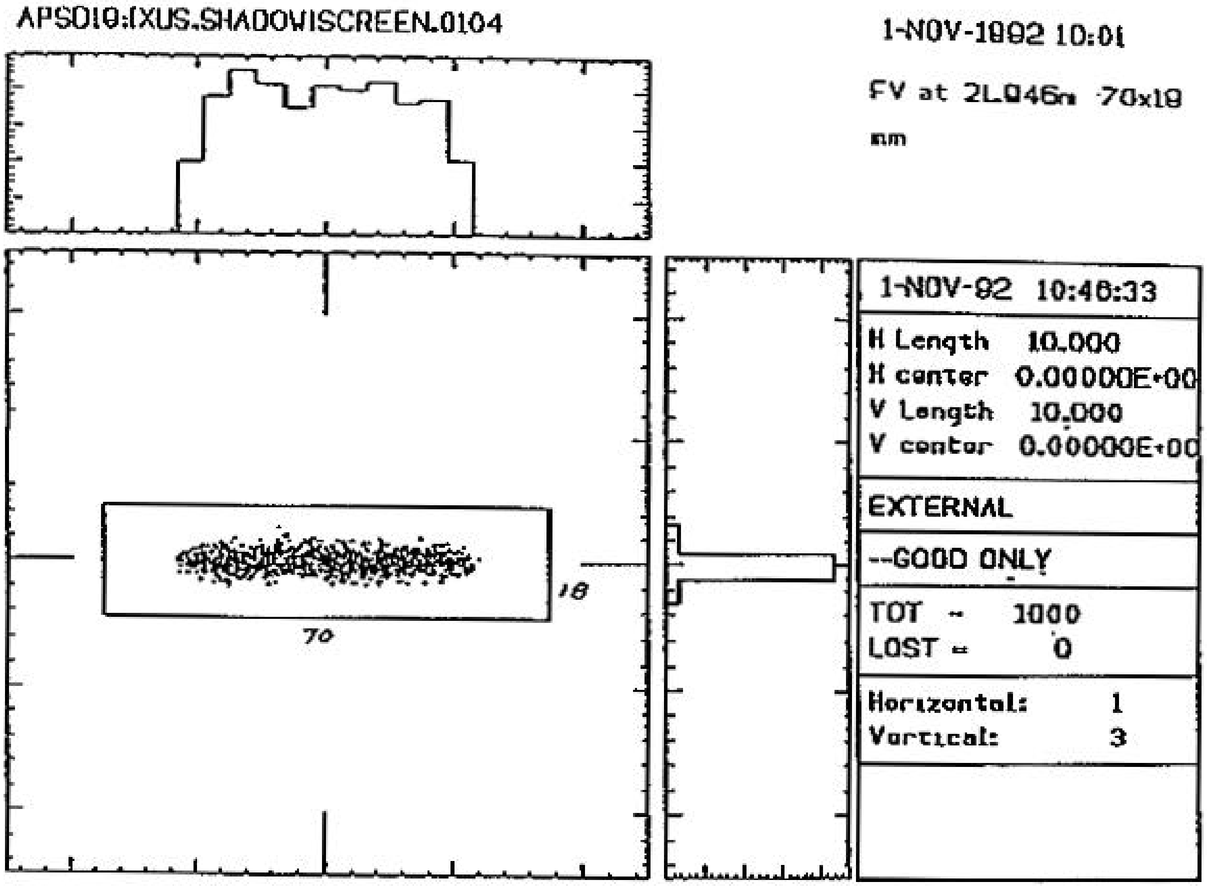


Figure 5e. SHADOW ray tracing for FV of the ID front end

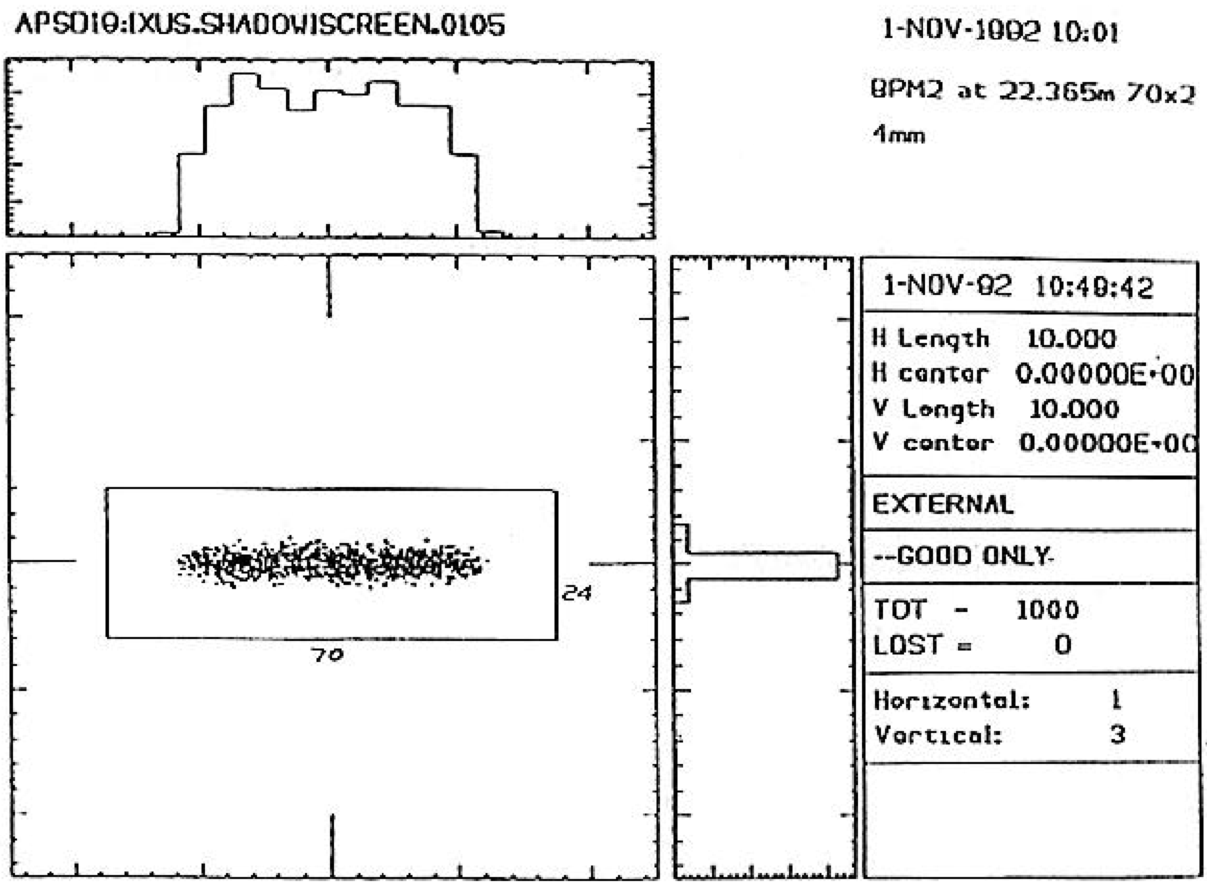


Figure 5f. SHADOW ray tracing for BPM 2 of the ID front end

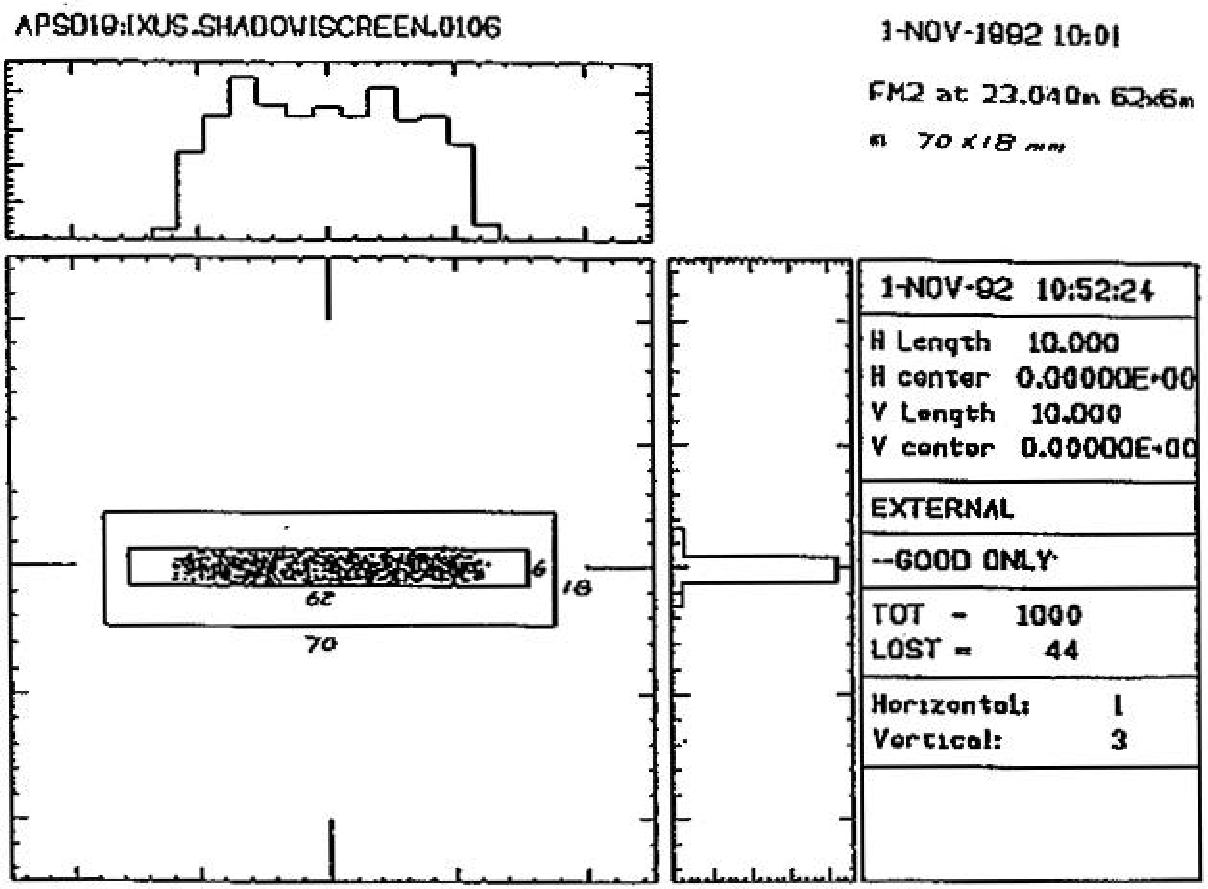


Figure 5g. SHADOW ray tracing for FM 2 of the ID front end

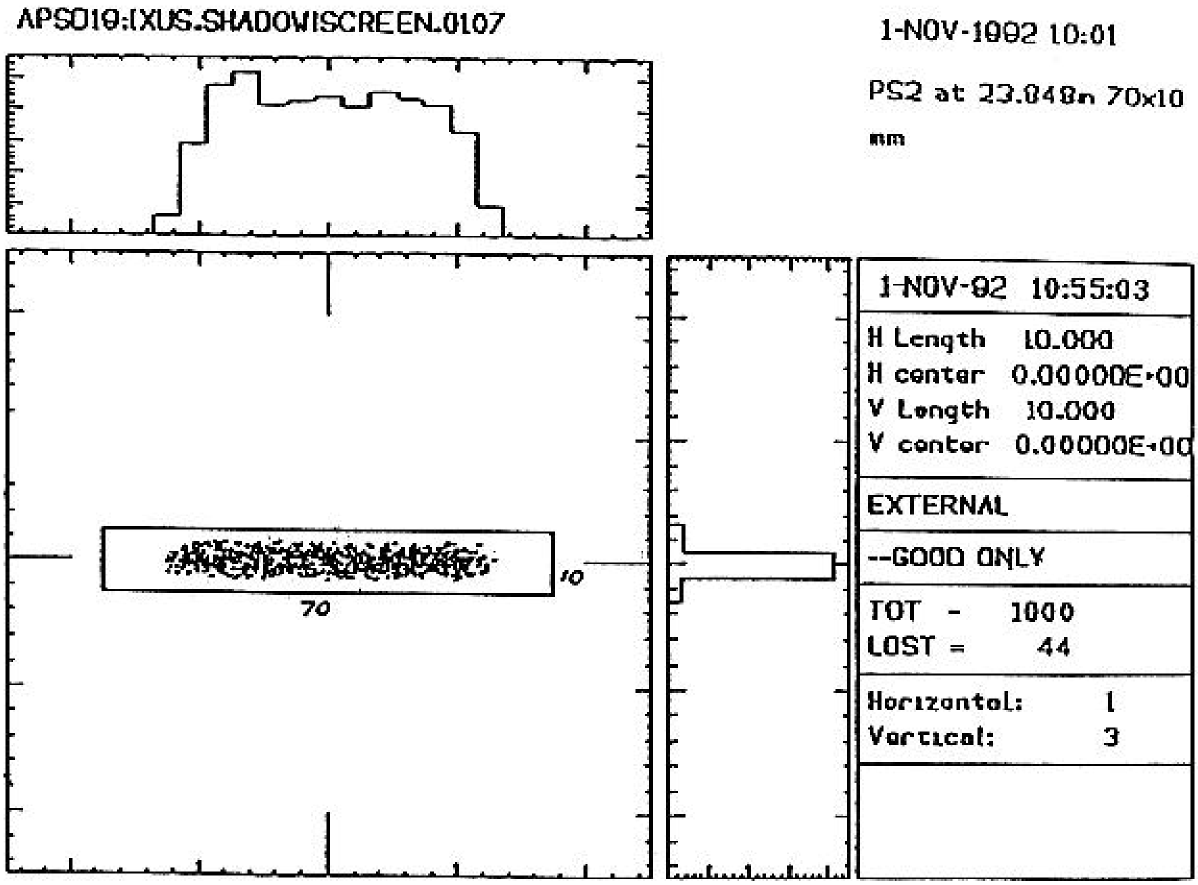


Figure 5h. SHADOW ray tracing for PS 2 of the ID front end

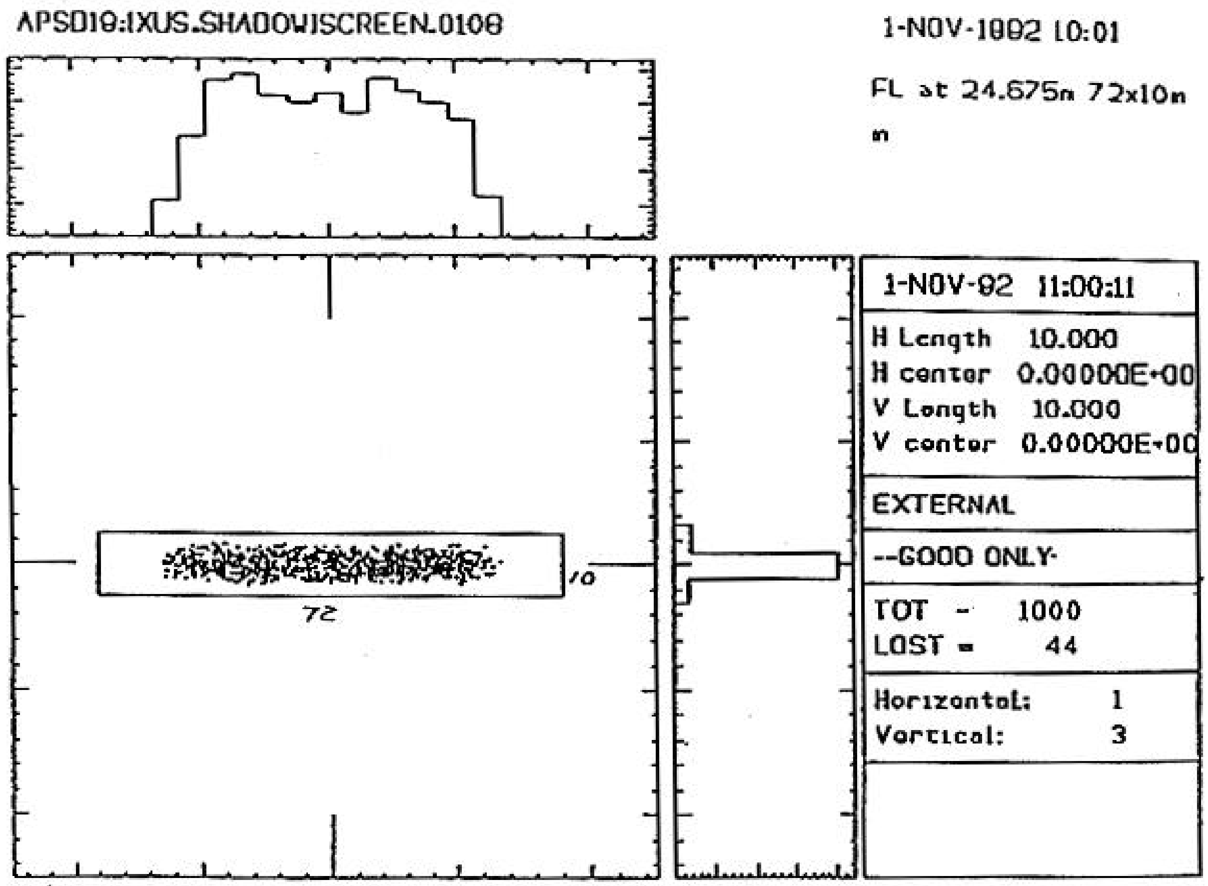


Figure 5i. SHADOW ray tracing for filter assembly of the ID front end

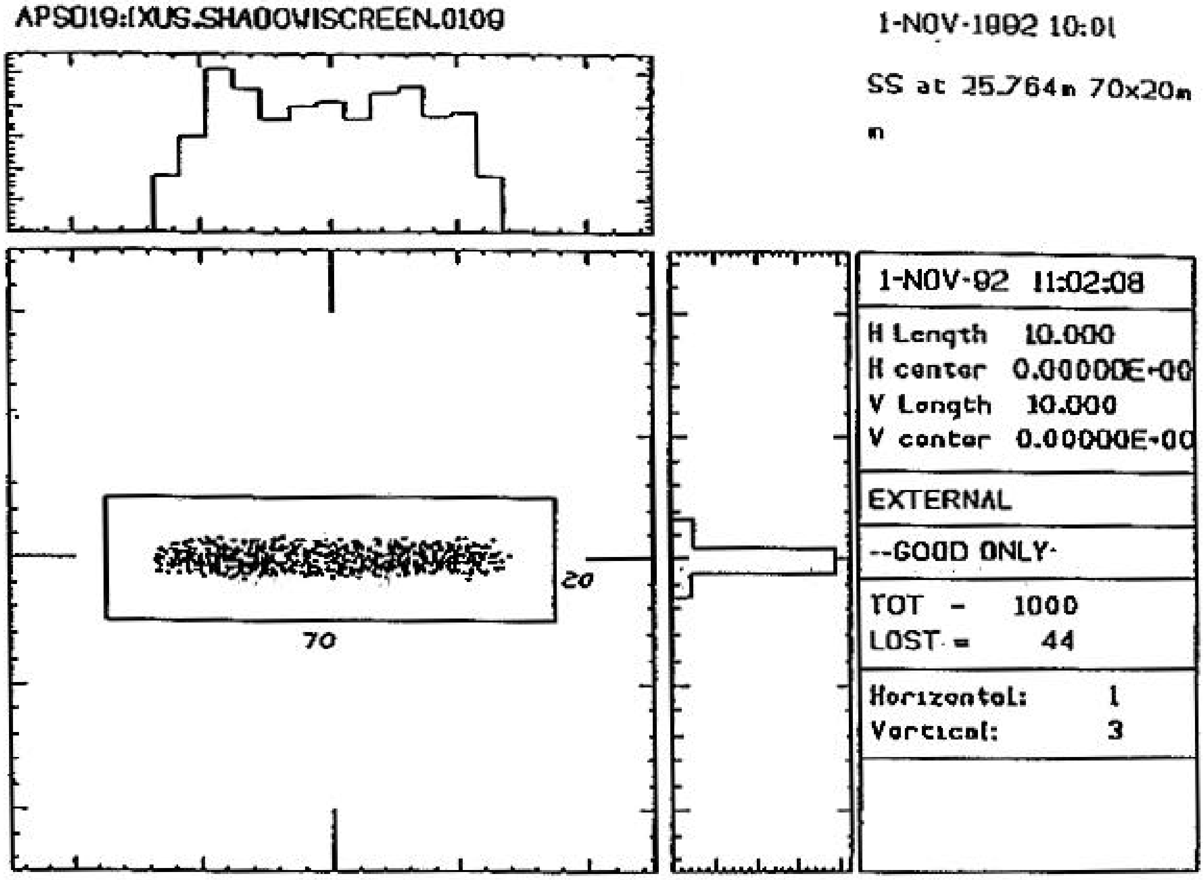


Figure 5j. SHADOW ray tracing for safety shutter/collimator of the ID front end

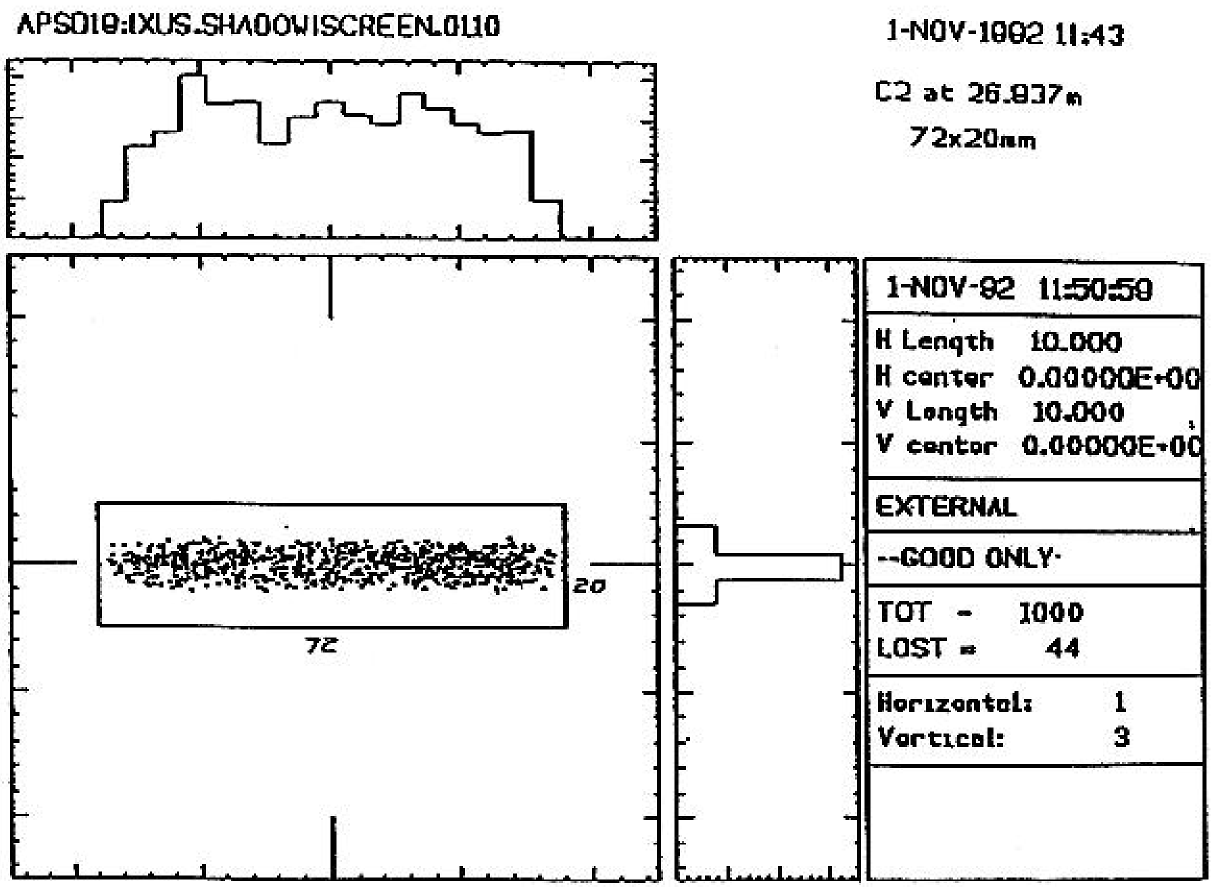


Figure 5k. SHADOW ray tracing for collimator 2 of the ID front end

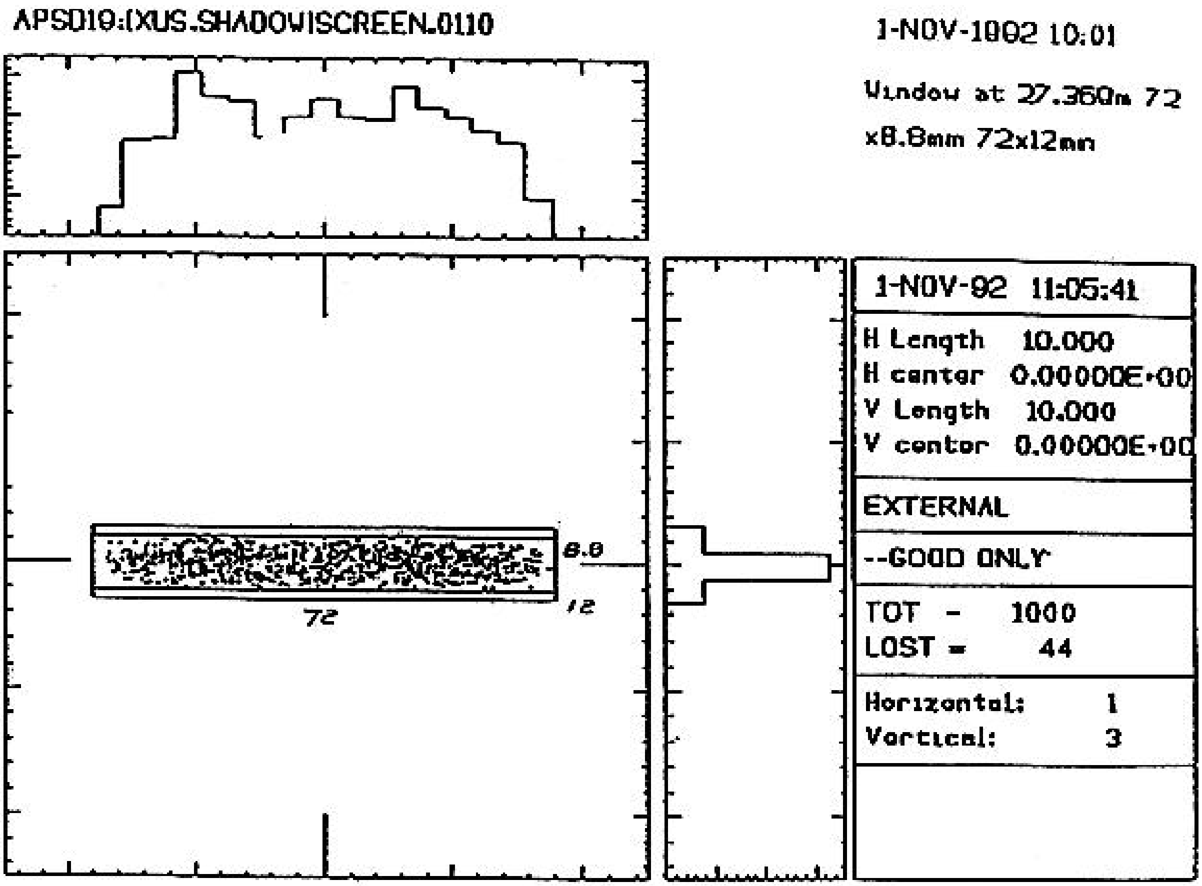


Figure 51. SHADOW ray tracing for window of the ID front end

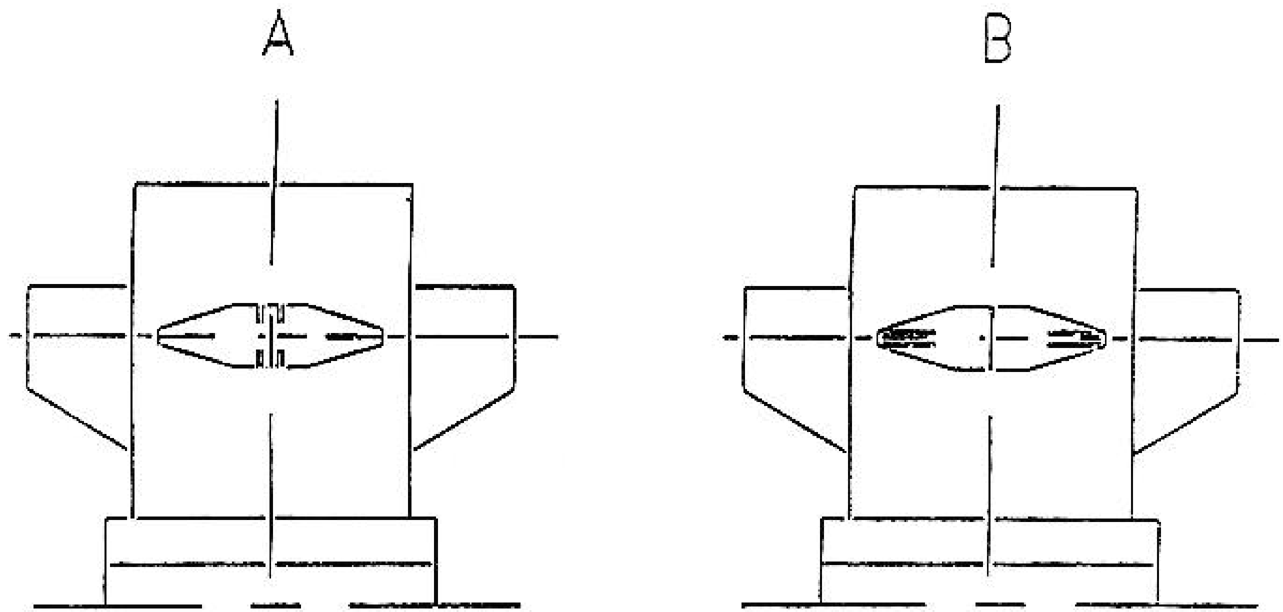


Figure 6. Schematic of the 6-Blade ID Front End PBPM Design

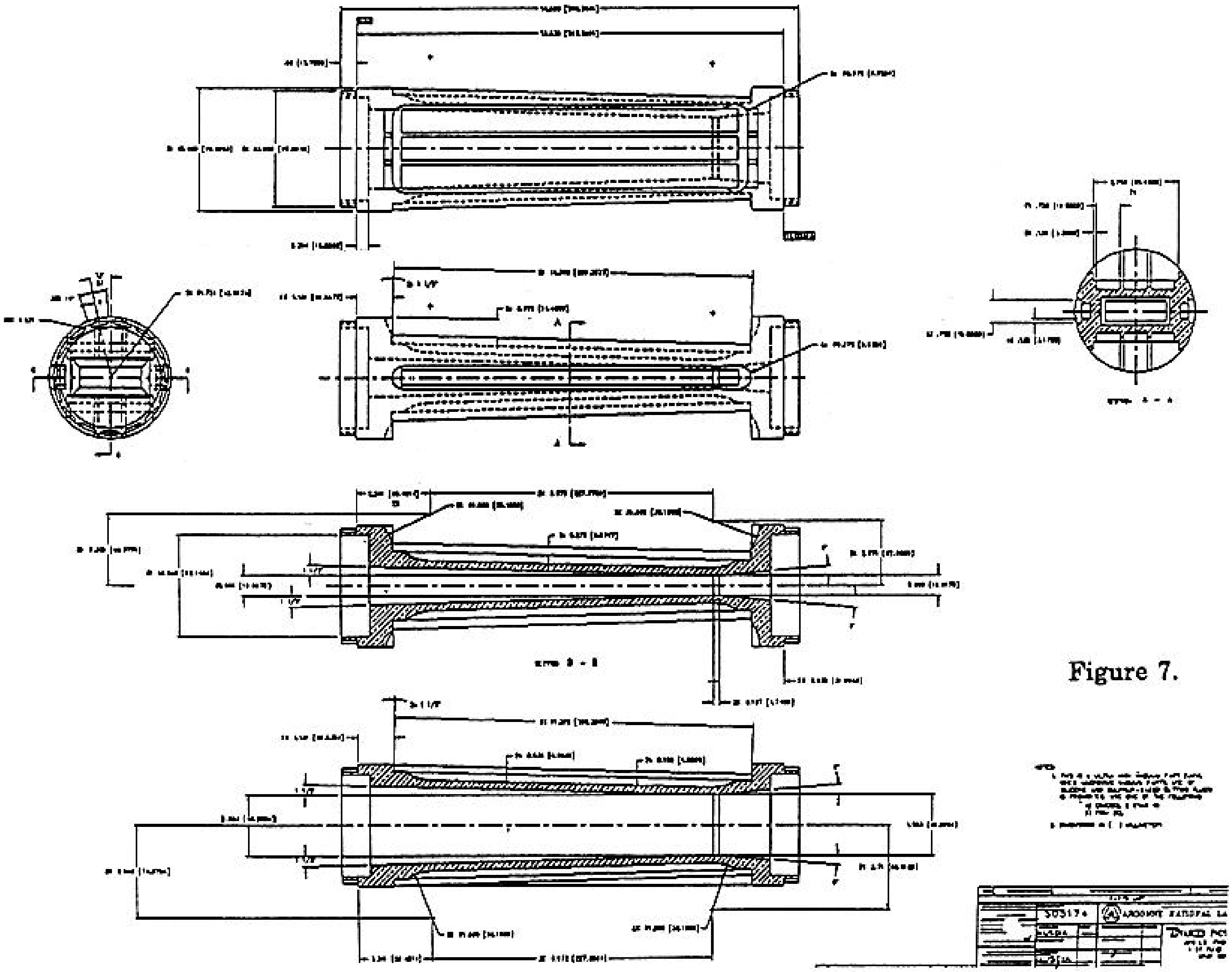
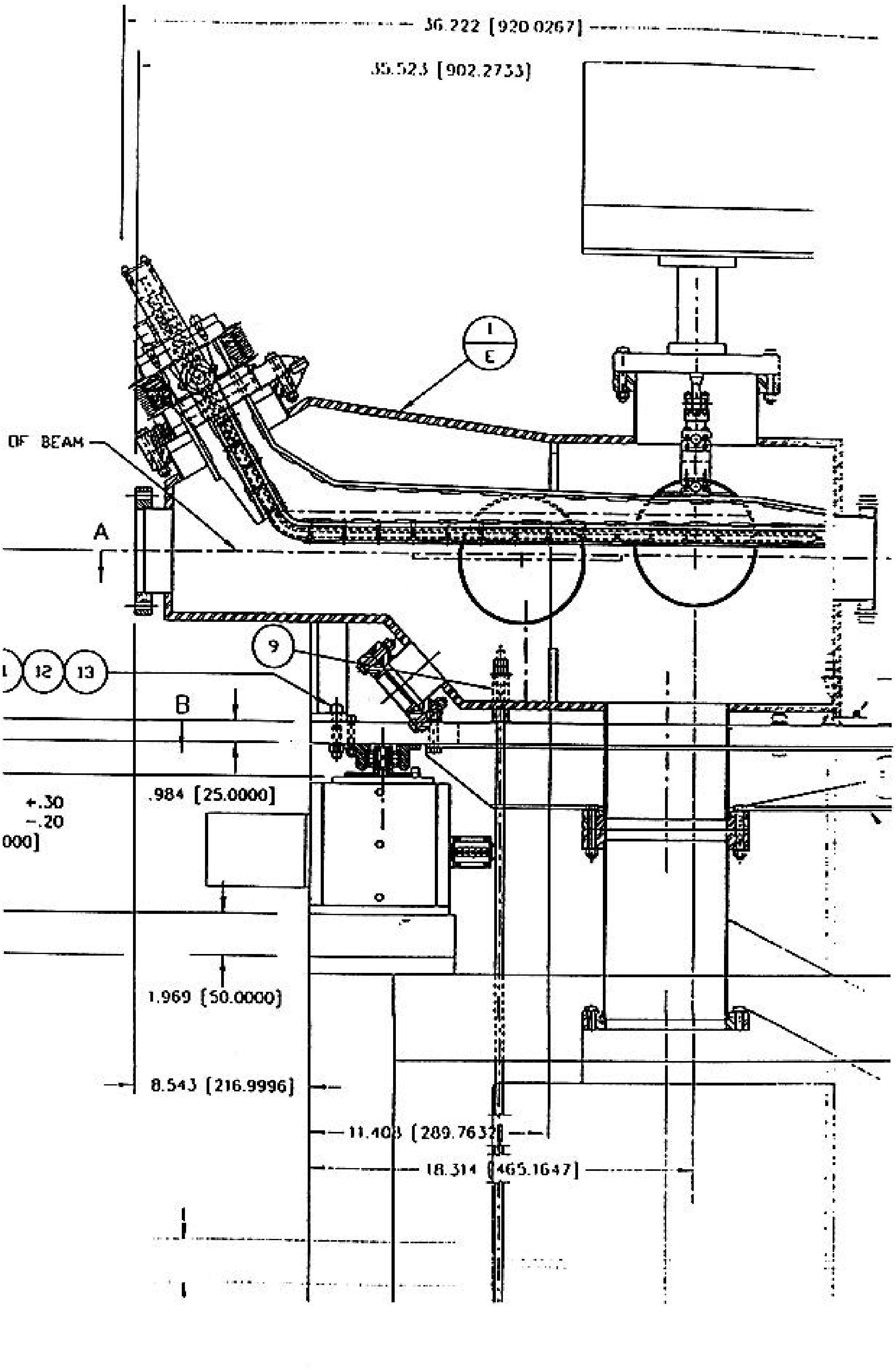


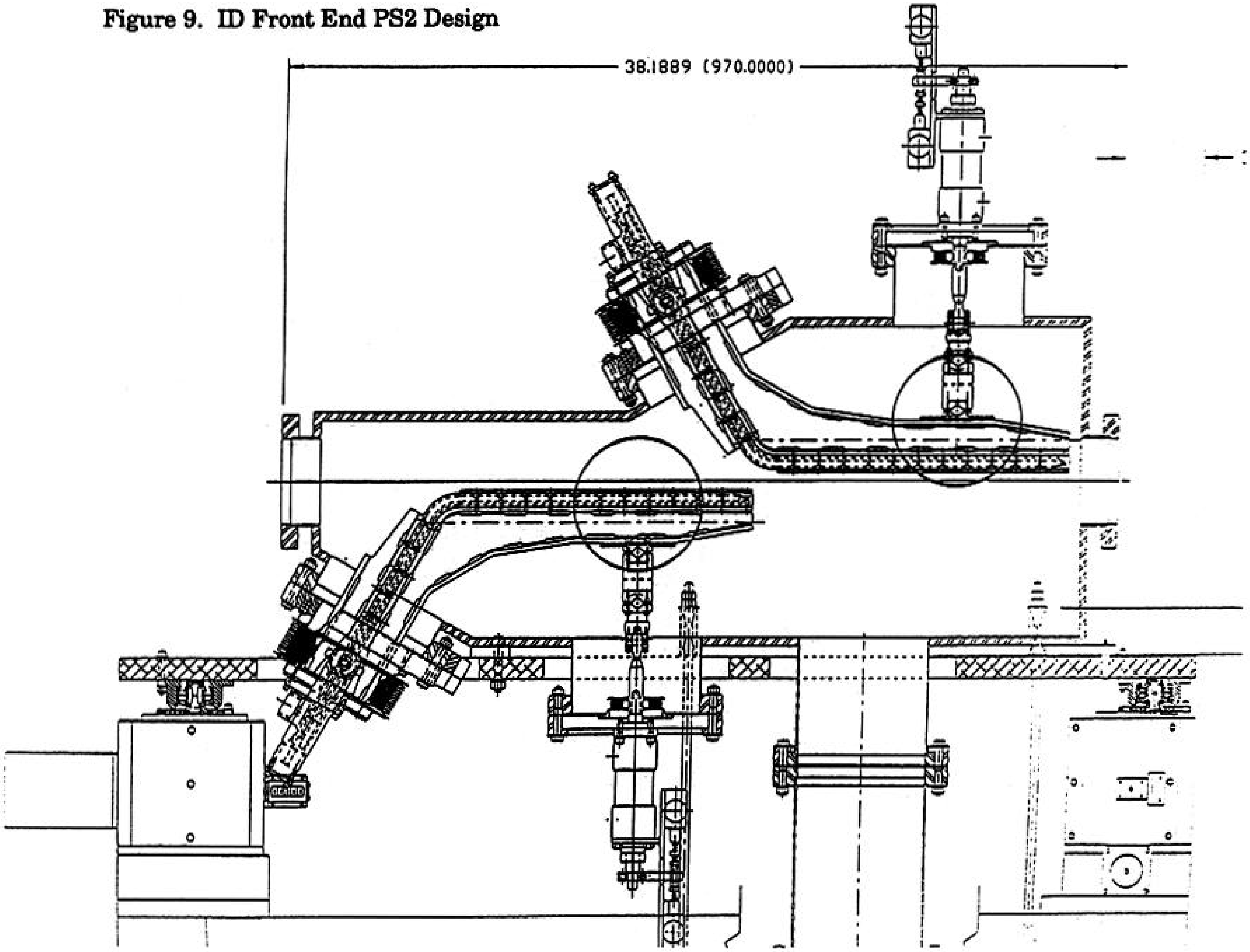
Figure 7.

Figure 8.



36.222 [920.0267]
35.523 [902.2733]
I
E
OF BEAM
A
9
12
13
B
.984 [25.0000]
+.30
-.20
000]
1.969 [50.0000]
8.543 [216.9996]
11.403 [289.7632]
18.314 [465.1647]

Figure 9. ID Front End PS2 Design



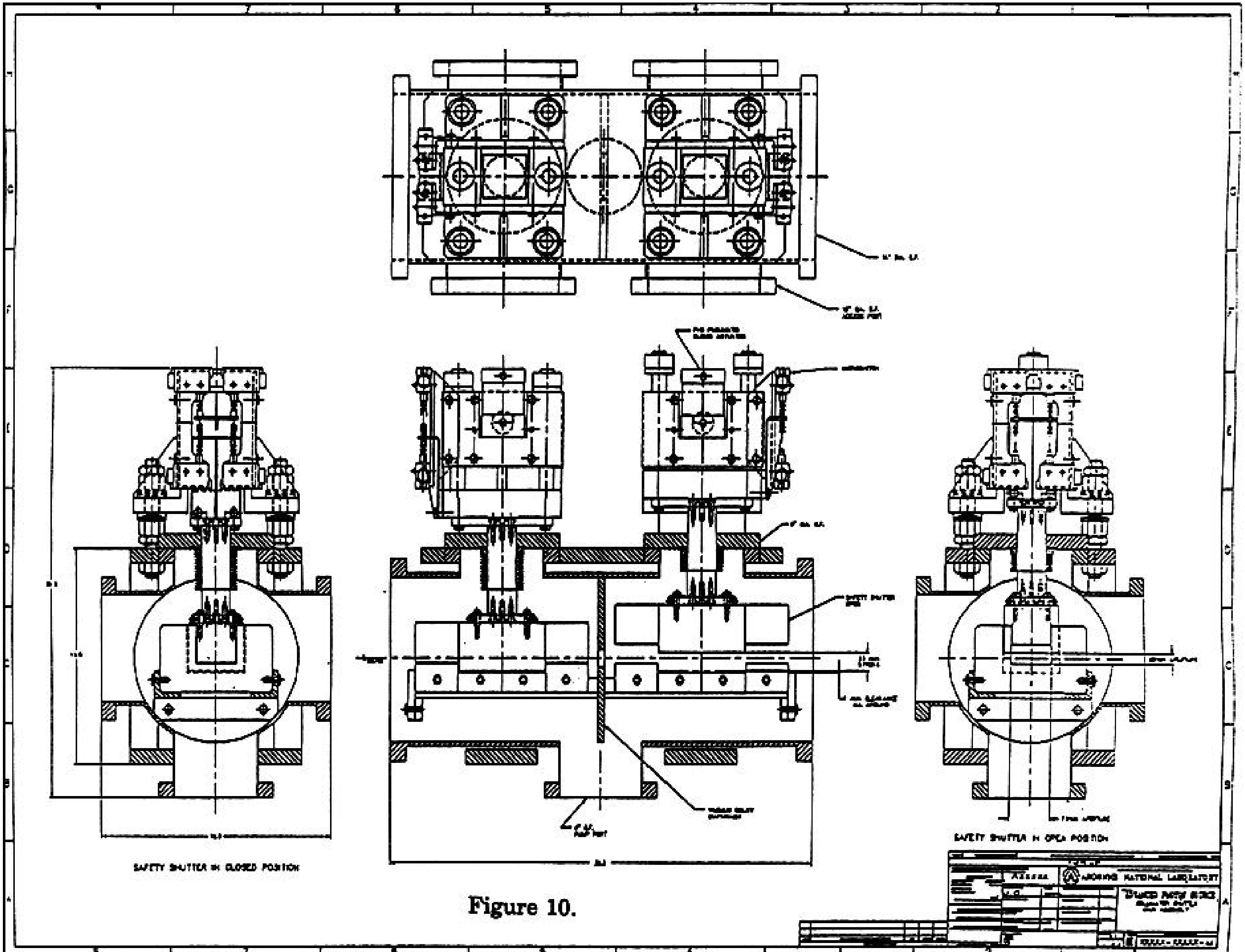

SAFETY SHUTTER IN CLOSED POSITION
SAFETY SHUTTER IN OPEN POSITION
ARGONNE NATIONAL LABORATORY

Figure 10.

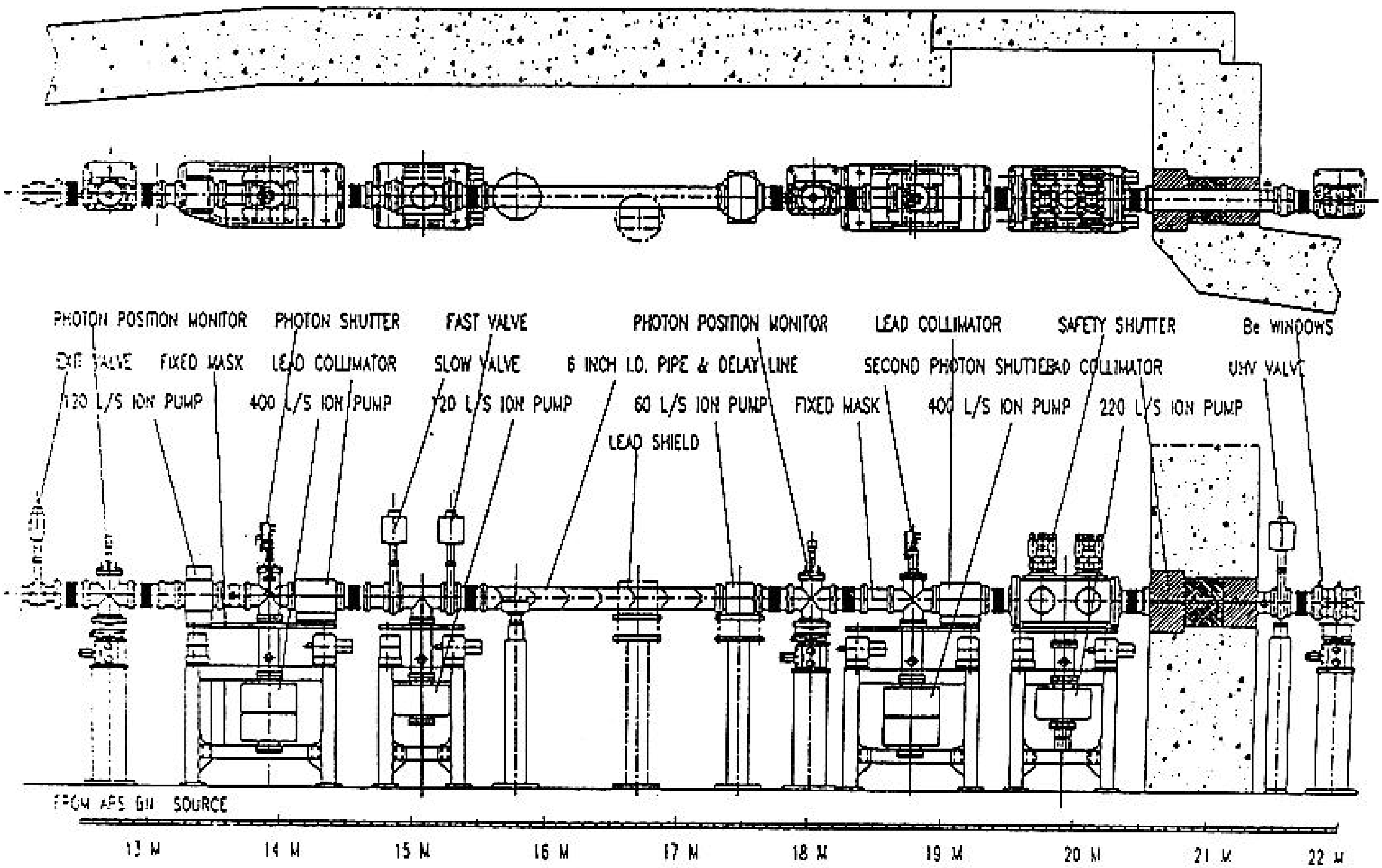


Figure 11. APS Bending Magnet Front End Layout

4. Creative Phase Ideas, Comments, and Actions

In this section, the outcome from the VE Workshop (Creative Phase) is summerized along with the actions (Judgment Phase) taken by the EC Group. Both are tabulated by the WBS numbers below.

WBS 1.4.1.2.1.1.3 ID Photon Shutters		**Advanced Photon Source Experimental Facilities Date January 1993**	**Creative Phase**	**Judgment Phase**
No.	**Creative Idea**		**Comments**	**Action**
1	Address the logical function of two blades in the second photon shutter (PS2). This should be done by considering operational scenarios and their role in personnel and equipment safety.		Simplifies the design and will reduce the cost.	PS2 has been designed with a single blade without loosing any of the functions or safety.
2	Thermal sensors should be implemented on the photon shutters.		Design improvement to provide equipment protection.	Has been included in the design.
3	Consider using in-vacuum sensors to indicate the position of the photon shutter in fail-safe detection.		Design alternative.	In-vacuum sensors increase maintenance time and hence alternatives are being evaluated that reside outside the vacuum.
4	There is no need to implement fast actuation of the photon shutter PS1.		Simplifies the component design and reduces cost.	The fast actuation will be eliminated from current design; R&D will be continued in anticipation of future needs.
5	In case of a catastrophic event, increase ID gap to reduce power on the FE components.		Provides secondary equipment protection safety capability.	Will be implemented to support commissioning activities to provide equipment safety (PS1 or storage ring vacuum chamber).

WBS 1.4.1.2.1.1.3 ID Photon Shutters	Advanced Photon Source Experimental Facilities Date January 1993		Creative Phase	Judgment Phase
No.	**Creative Idea**		**Comments**	**Action**
6	If the catastrophic event is due to a vacuum failure, the positron beam could be dumped in case of a fast leak; the ID gap could be increased (see 5) in case of a slow leak. The capability to evaluate the leak is necessary to reduce the frequency of beam dumps.		Design improvement.	Will be implemented (see action under 5).
7	If positive actions are taken on items 5 and 6 above, can PS1 be replaced by a simple photon shutter from the BM front end?		If possible, will reduce cost.	Although the actions on items 5 and 6 are positive, PS1 will not be replaced. At least one component in the front end should fully handle the heat load.
8	The water flow monitors should be included in the equipment safety loop.		Design enhancement.	The water flow monitors are included in the equipment safety and, in abnormal events, shut down the front end. In catastrophic cases, they will dump the beam.
9	In all the actuators on the photon shutters, use of a double-leaf spring will eliminate two flexural couplings.		Design improvement that might lead to cost savings.	The spring-leaf mechanisms can only provide 1-2 s actuation speed. This might be adequate initially, but will have to be replaced if faster response is needed. In anticipation of such needs in the future, the idea has been dropped.

WBS 1.4.1.2.1.1.4 ID Photon Beam Position Monitor	**Advanced Photon Source Experimental Facilities Date January 1993**	**Creative Phase**	**Judgment Phase**
No.	**Creative Idea**	**Comments**	**Action**
1	Develop separate fixed-blade designs for undulator and wiggler beamlines.	Simplifies the design.	Redesign work is being carried out.
2	Current design should be used on beamlines that will receive radiation from either an undulator or a wiggler.	OK.	No action needed.
3	Instead of six-blade configuration for the photon BPM, develop configurations with fewer blades.	This will reduce the cost of blades and electronics.	For wiggler, four blades will work. More R&D needed for undulators.
4	Should provision be made for six blades in the assembly unit ?	Simplifies future needs.	Not cost effective.
5	Instead of Kiethly electrometers, see if low cost alternatives with self adjusting gains could be used.	Will reduce cost.	Available information (Knapp and Montano) leads to additional market search and/or development.
6	Stepping motors for the BPM stages should be provided with clutch to clamp, so that the motors can be turned off.	Design improvement.	Implemented using information from D. Gennarro.

WBS 1.4.1.2.1.1.1 and 5 ID Fixed Masks	Advanced Photon Source Experimental Facilities Date January 1993		Creative Phase	Judgment Phase
No.	**Creative Idea**		**Comments**	**Action**
1	Consider matching upper and lower halves of the Fixed Masks and then brazing the two halves. This will eliminate EDM work on a single piece.		Less labor and may be cheaper.	The work is not cheaper than EDM work, and the solution is not reliable.
2	Flange end can be brazed to a shorter neck of the Fixed Masks, reducing the special machining. Make the square-to-round transition at the end of fixed masks in stainless steel instead of copper.		Cost savings possible.	The design is now altered to include the recommendation.

WBS 1.4.1.2.1.1.8 ID Safety Shutters	Advanced Photon Source Experimental Facilities Date January 1993	Creative Phase	Judgment Phase
No.	**Creative Idea**	**Comments**	**Action**
1	Evaluate the role of safety shutters and the need for two in the operational and catastrophic scenarios.	Design assessment.	The need for two shutters and the logic has been established.
2	Address the economy of the current design in which the safety shutters contain the collimating function.	Possible cheaper solution.	The design of separating the two functions is being evaluated.
3	Include in-vacuum thermal sensors and their use in the logic of safety shutter operation.	Design assessment.	Under study.

WBS 1.4.1.2.2.1.4 BM Photon Beam Position Monitors	**Advanced Photon Source Experimental Facilities Date January 1993**	**Creative Phase**	**Judgment Phase**
No.	**Creative Idea**	**Comments**	**Action**
1	The photon beam position monitor on a BM need only supply the vertical position information. Simplify the current photon BPM design.	Cost reduction possibilities.	New design provides only the required motion.
2	The horizontal and/or the rotational stages supporting the BPM could be eliminated.	Cost reduction possibility.	New design has eliminated the horizontal stage. The rotational stage will be required to perform BPM alignments at large stored currents.
3	Attempt should be made to mount BPM1 on the first fixed mask.	Possible cost reduction and space saving.	The design becomes complex and the cost saving is minimal.

WBS 1.4.1.2.2.1.3 BM Photon Shutters	Advanced Photon Source Experimental Facilities Date January 1993	Creative Phase	Judgment Phase
No.	**Creative Idea**	**Comments**	**Action**
1	Braze the shutter stem to a separate tube outside the vacuum.	Construction simplicity.	Not cost effective to implement.
2	Shorten the flange neck to shorten the tube height.	Construction simplicity.	Design work was performed and the cost saving was found to be marginal; will not be implemented.
3	Decrease the inclination angle of PS1 and PS2 relative to beam from 45 degrees to a smaller value.	The purpose of suggestion is to increase the safety margin during operation.	The safety margin is more than adequate even at a 45 degree inclination.

WBS 1.4.1.2.2.1.1 BM Fixed Masks		Advanced Photon Source Experimental Facilities Date January 1993	Creative Phase	Judgment Phase
No.	**Creative Idea**		**Comments**	**Action**
1	Address applicability of ideas presented for ID Fixed Masks WBS 1.4.2.1.1.1 and 5.			Actions indicated under WBS 1.4.2.1.1.1 and 5 will be taken.

WBS 1.4.1.2.2.1.5 BM Safety Shutters		Advanced Photon Source Experimental Facilities Date January 1993	Creative Phase	Judgment Phase
No.	**Creative Idea**		**Comments**	**Action**
1	Address applicability of ideas presented for ID Fixed Masks WBS 1.4.2.1.1.8.			Actions indicated under WBS 1.4.2.1.1.8 will be taken.

WBS 1.4.1.2.1.2 ID Front End Vacuum System	Advanced Photon Source Experimental Facilities Date January 1993	Creative Phase	Judgment Phase
No.	**Creative Idea**	**Comments**	**Action**
1	Consider the use of titanium sublimation pumps (TSPs) at strategic places. Remember that the TSPs are fragile and that experience shows that ion pumps are superior to TSPs in along run.	Cost saving is possible with the use of TSPs.	Newly introduced demountable NEGs provide an even better solution. Such NEG pumps are being tested.
2	Use one power source to operate a number of ion pumps.	Cost saving is probable if this can be adapted.	This is not feasible because sources will be used to monitor the pressure.
3	Replace 400 l/s pumps with a number of smaller pumps.	More reliability; cost savings will have to be addressed.	Limitation of space in the front end does not always permit introduction of smaller pumps at more places. A design with 220 l/s, 170 l/s, and NEG pumps is being developed.
4	Keep RGA and ion pumps separated. Preferably, locate RGA close to the storage ring near BPMs.	Design enhancement to obtain true pressure in the storage ring.	This suggestion has been included in the design.
5	Use power sources as monitors for the ion gauges.	Cost saving possibility.	See comment under 2 above.
6	Reconsider the need of an upstream ion pump near the storage ring to increase pumping efficiency. Also, consider the use of a TSP at this location.	Design improvement.	Redesign work is in progress.
7	There is no need for 10^{-9} Torr vacuum in the entire front end because the long length and constrictions provide adequate differential pressure.	Cost saving possibility due to reduced pumping requirement of front ends.	Redesign work is in progress.

WBS 1.4.1.2.2.2 BM Front End Vacuum System		Advanced Photon Source Experimental Facilities Date January 1993	Creative Phase	Judgment Phase
No.	**Creative Idea**		**Comments**	**Action**
1	Address applicability of ideas presented for ID Front End Vacuum System WBS 1.4.1.2.1.2.			Actions indicated under WBS 1.4.1.2.1.2 will be taken.
2	Evaluate whether a 6-inch-diameter vacuum delay line should be added to the BM front end.		Design enhancement.	Design work in progress.

WBS 1.4.1.2 Front Ends - General		Advanced Photon Source Experimental Facilities Date January 1993	Creative Phase	Judgment Phase
No.	**Creative Idea**		**Comments**	**Action**
1	Protectors or mechanical guards should be installed on all vacuum feedthroughs.		Design enhancement.	Included in the current design.
2	Provide the capability to install padlocks on all photon shutters, safety shutters, etc., for lockout/tagout needs of commissioning, operation, and maintenance.		Design enhancement.	Included in the current design.

WBS 1.4.1.2.3 Front End Supports	**Advanced Photon Source Experimental Facilities Date January 1993**	**Creative Phase**	**Judgment Phase**
No.	**Creative Idea**	**Comments**	**Action**
1	Consider simpler design for all supports, for example, screw thread/jack system design provided by Hans Jostlein.	Could lead to cost savings because of the high multiplicity of supports.	The designs have been simplified by regrouping FM1-PS1 and Collimator 1. Most supports now have only manual motion. Roller bearings have been eliminated where ever possible. This redesign has been accomplished without loss of quality.
2	Supports do not need linearity; require only repeatability in position.	Has potential for cost reduction.	Folded in the new design.
3	The design of the ball transport system is good, but prototype should be tested on the Storage Ring tunnel floor.	Design check.	The ball transport system may not be needed because a commercial system with very low boy is available.
4	Storage Ring tunnel floor might have to be covered with a steel sheet to correct an uneven floor and to accommodate ball- or air-bearing movement.	Deign enhancement during assembly, commissioning, etc.	Will be considered if needed.
5	Develop clutch system to lock various supports.	Design improvement.	Included in the new design.
6	Perform vibration analysis with correct device simulation.	Design enhancement.	Work will be done soon after redesign is complete.
7	Cover the insulation on the supports for photon BPMs with a metal sheet.	Design enhancement.	Included in the new design.

WBS 1.4.1.2.1.5 and 1.4.1.2.2.5 FE Survey and Alignment	Advanced Photon Source Experimental Facilities Date January 1993	Creative Phase	Judgment Phase
No.	**Creative Idea**	**Comments**	**Action**
1	Put meter marks on the Experiment Floor, preferably on either side of the line of photon beam so that they are visible even after the beamline hardware is mounted.	Design enhancement.	Included in the task list.
2	Install all monument markers on the vacuum chambers of front ends, in addition to mounting support stages.	Design enhancement.	Included in the current design.

WBS 1.4.1.2 Ratchet Wall Penetrations		Advanced Photon Source Experimental Facilities Date January 1993	Creative Phase	Judgment Phase
No.	**Creative Idea**		**Comments**	**Action**
1	Provide large aperture to the transport tube inside the ratchet wall so that the alignment of the shielding material can be simplified.		Design enhancement.	The redesign is under study.
2	Make the design of filler material simple.		Design enhancement.	The redesign is under study.

WBS 1.4.1.2.1.4.8 1.4.1.2.2.4.8 Front End - Test Equipment	Advanced Photon Source Experimental Facilities Date January 1993	Creative Phase	Judgment Phase
No.	**Creative Idea**	**Comments**	**Action**
1	Optimize the number of video cameras in the front end.	Possible savings.	Included in the new design.

5. Front End Layout Resulting from the Value Engineering Process

The results of the value engineering process are illustrated in the form of the current layout of the ID and BM front ends. These are presented in Figs. 12 and 13, respectively, and are described briefly here.

ID Front Ends

The key design changes include: the configuration of the first 120 l/s pump and the RGA; integration of the FM1 and the PS1; design of the PS2; the support system and the kinematic mounts; and the PBPM designs. Integrating the FM1 and the PS1 and combining the first lead collimator with the vacuum valves results in one less support table in the ID front end. The kinematic mounts are now largely mechanically driven rather than driven by stepping motors resulting in substantial cost savings. The previous two-absorber-blade system of the PS2 has been reduced to a single-blade configuration as is present in PS1, again with substantial cost savings. For improved performance, the first 120 l/s ion pump and the integrated RGA is connected to the vacuum transport in an in-line fashion. The new designs for the PBPMs use fixed but resettable horizontal blade gaps in lieu of the adjustable horizontal drive, which was considered previously and is now optional. The adjustable horizontal drive is the subject of continuing research and development. Although not shown in Fig. 12, the post-value engineering vacuum analysis has shown that the ion pumps standardized around 170 l/s with removable NEG pumps will result in superior performance, significant reduction in maintenance, and longer range operational cost when compared to the recommended smaller pumps with TSPs. Such pumps have been adopted in the front end designs.

BM Front Ends

In the areas of vacuum pumping, support systems, and kinematic mounts, the design of the BM front ends also benefited from the value engineering exercise. In addition, the PBPM stages have been made simpler by providing only a vertical stage and two rotations.

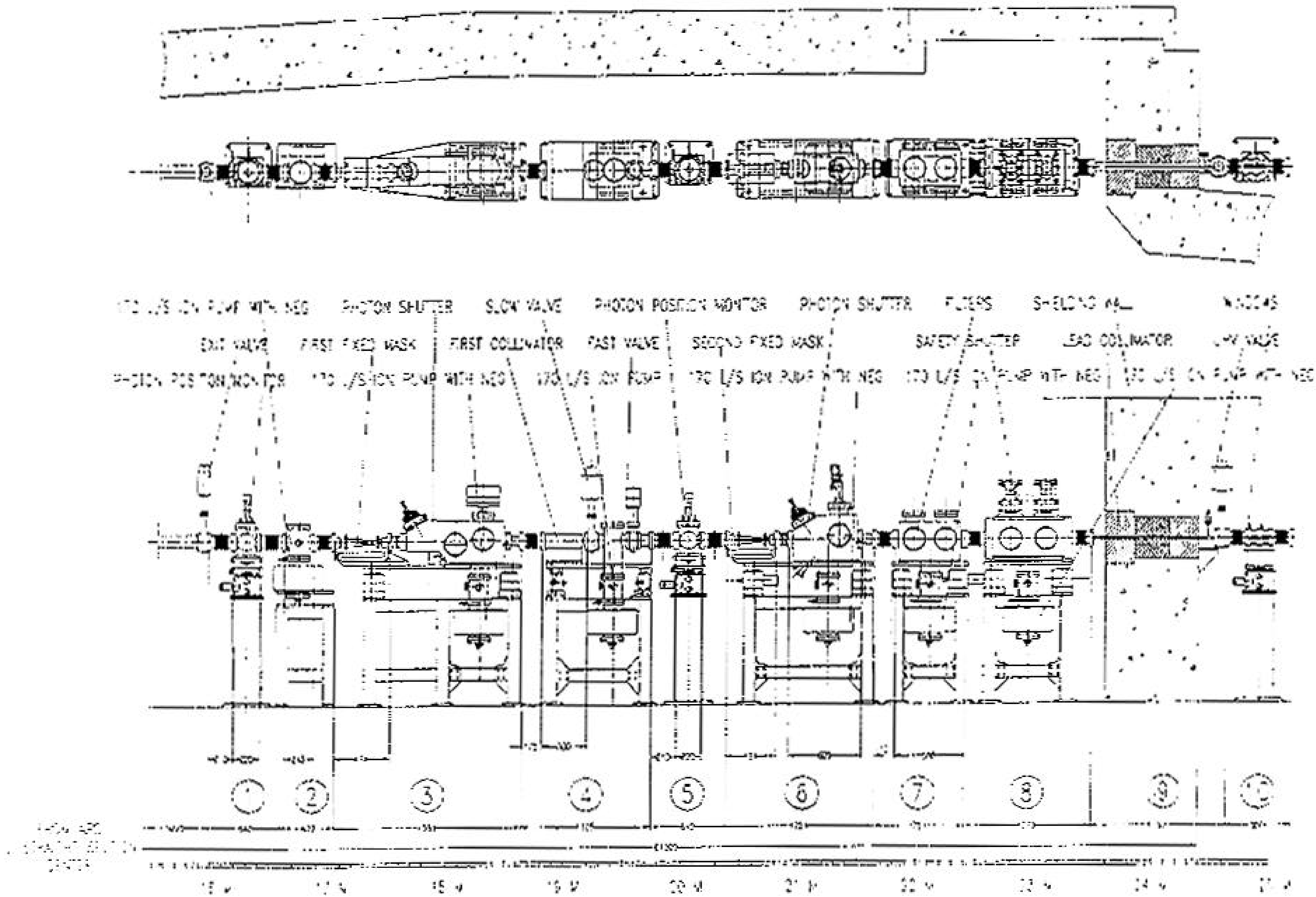


Figure 12. APS INSERTION DEVICE FRONT END GENERAL LAYOUT

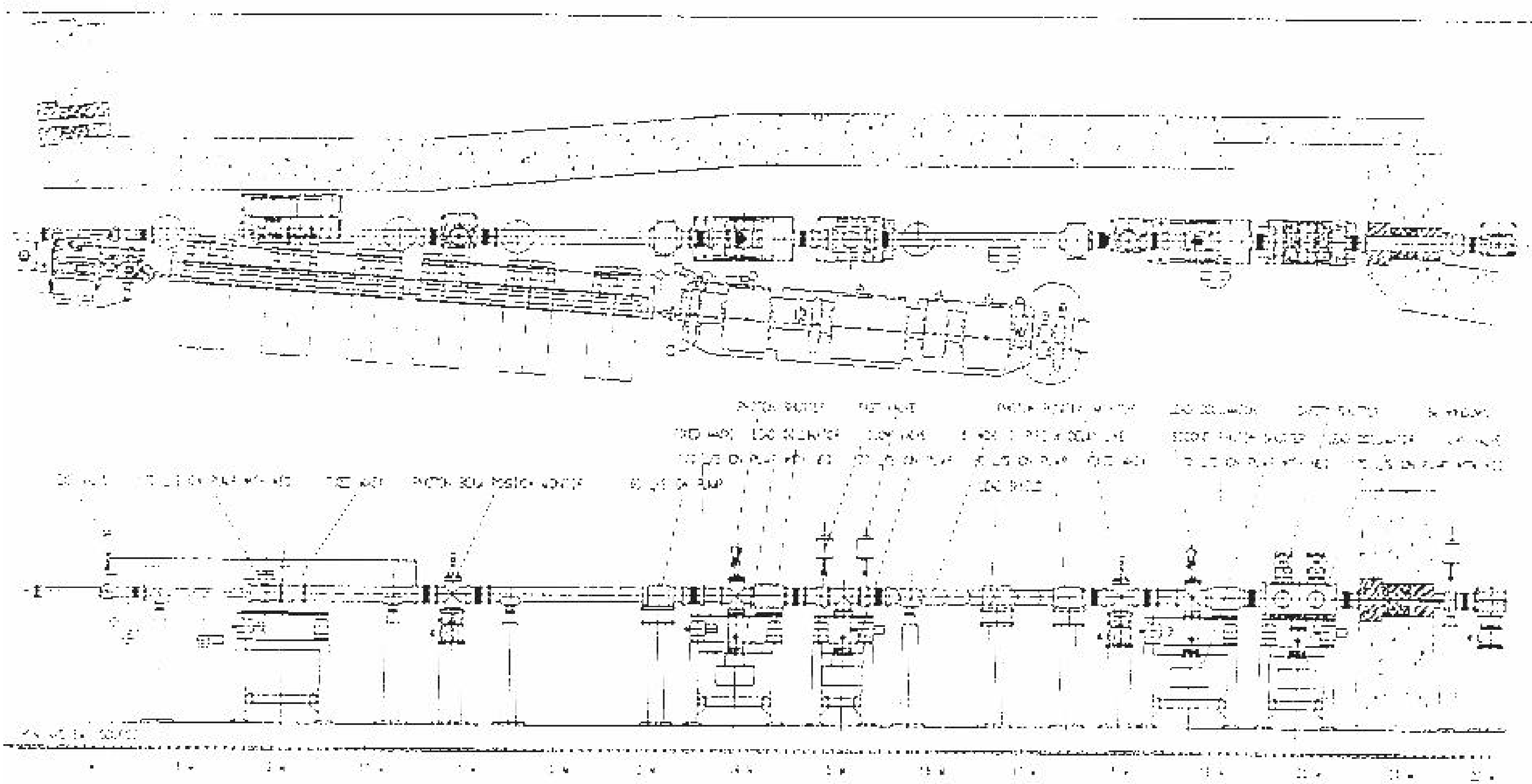


Figure 13. APS BM FRONT END GENERAL LAYOUT

6. Creative Phase Ideas Requiring Design Studies

There are many topics that will be addressed in detail as the Title II design of the ID and the BM front ends are completed. A list of some of these topics includes:

- design and testing of photon BPM configurations with less than six blades for the use on undulator beams,
- evaluation of the availability of low cost alternatives to Kiethly electrometers,
- design of fast actuators for PS1 for future applications,
- usefulness of separating collimating and safety shutter functions of the past design,
- design of the in-vacuum thermal sensors in the safety shutters,
- complete front end vacuum design to evaluate various trade off in pump sizes and types,
- need for a delay line in the BM front end,
- vibration analysis of realistic supports,
- redesign of filling material geometry in the ratchet wall beamline port.

7. Value Engineering Cost Benefit Analysis

In the accompanying table the pre- and post-Value Engineering costs are tabulated for those WBS items identified during the workshop. The pre-value engineering cost bases are those estimated for the Title I Review of the APS front ends by the Department of Energy (Nov. 1991).

ID Front Ends

A review of the cost benefit analysis indicates that the value engineering process resulted in substantial cost saving in the ID front end PS2, pumps, support system kinematic mounts, and PBPM stages. A combination of design/manufacturing improvements and elimination of the lower blade in PS2 lowered the cost by $238.2K. Major cost savings resulted from the conversion of most of the stepping motor kinematic drives to cheaper but equally effective mechanical-type drives. In the ID front ends, this item alone saves about $419.6K out of the total $860K savings (as indicated in the last variance column of the cost-benefit table). The balance of the cost cutting occurred through the choice of vacuum pumps. The value engineering panel had recommended smaller ion pumps with TSPs. Our own post-value engineering investigations proved that an ion pump system for the front ends that is standardized around 170 l/s ion pumps (in lieu of the previous 220 and 440 l/s pumps) with mountable NEG pumps (600 l/s) would give us both performance and price advantages. The resulting savings in the ID front ends is $116.3K.

BM Front Ends

The only benefits derived from this value engineering exercise with respect to the BM front ends occur in the PBPMs and their stages. Elimination of one horizontal stage in the BM PBPM stages resulted in $284.1K savings. With the cost cutting in the PBPM design, the total value engineering cost savings in the BM front ends amount to $310.7K.

In summary, the value engineering exercise in all APS front ends resulted in approximately $1171K savings, as reflected in the accompanying table.

VALUE ENGINEERING COST-BENEFIT ANALYSIS

WBS	Element Name*	Percentage Reduction from Title I Costs Due to VE
	ID FRONT ENDS	
1.4.1.2.1.6	ID Photon Shutter 2	22
1.4.1.2.1.2.1	Pumps	10
1.4.1.2.1.1.10	ID FE Kin. Mounts	32
1.4.1.2.1.1.11	ID BPM Mounts	14
	BM FRONT ENDS	
1.4.1.2.2.1.4	BM BPMs	3
1.4.1.2.2.3.3	BPM Mounts	45

*Element to which value engineering was applicable.

Appendix A

Value Engineering Workshop

November 5-6, 1992
Argonne National Laboratory
Bldg. 362, Rm. E356

Thursday, November 5, 1992

9:00-9:30	Workshop Plan	Management
9:30-10:15	Front End Design Overview	Tunch M. Kuzay
10:15-10:30	Break	
	Information Phase on Current Technical Specifications and Designs	
10:30-11:30	Front End Components	Deming Shu
11:30-11:50	Front End Vacuum	Robert Nielsen
11:50-12:10	Front End Support Design, Alignment Issues and the Ratchet Wall Penetration Design	Juan Barraza
12:10-13:30	No Host Lunch Break	
13:30-13:50	Front End Safety/Interlock Design	Nick Friedman
13:50-15:15	Cost Base Discussions	Tunch M. Kuzay
15:15-15:30	Break	
15:30-17:30	Creative Phase	Committee/EC

Friday, November 6, 1992

8:30-10:00	Judgment Phase (Ranking of Ideas in Creative Phase)	Committee/EC
10:00-10:30	Break	
10:30-12:00	Development Phase (Workable Solutions)	Committee/EC
12:00-13:00	No Host Lunch	
13:00-15:00	Recommendations Phase	Comm/Mngmt/EC
15:00-15:30	Wrap-up, Draft Report	Comm/Mngmt/EC

Appendix B

Work Breakdown Structure (WBS)
for the Beamline Front Ends

1.4.1.2	**BEAMLINE FRONT ENDS**
1.4.1.2.1	**ID Front Ends**
1.4.1.2.1.1	**Front End Component Assemblies**
1.4.1.2.1.1.1	Fixed Mask Assembly and Enclosures
1.4.1.2.1.1.2	Lead Collimators and Housing
1.4.1.2.1.1.3	Photon Shutters, Enclosures and Monitoring
1.4.1.2.1.1.4	Photon Beam Position Monitor Assembly and Enclosures
1.4.1.2.1.1.5	Second Fixed Mask Assembly and Monitoring
1.4.1.2.1.1.6	Second Photon Shutter
1.4.1.2.1.1.7	Thermal Filters, Filter Assembly and Monitoring
1.4.1.2.1.1.8	Safety Shutter Assembly
1.4.1.2.1.1.9	Vacuum Window Assembly
1.4.1.2.1.2	**ID Front End Vacuum**
1.4.1.2.1.2.1	Pumps
1.4.1.2.1.2.2	Isolation Valve
1.4.1.2.1.2.3	Fast Valve and Monitoring
1.4.1.2.1.2.4	Slow Valve
1.4.1.2.1.2.5	Vacuum Monitoring Equipment
1.4.1.2.1.2.6	Bakeout System
1.4.1.2.1.2.7	Vacuum Flanges and Beam Pipes
1.4.1.2.1.2.8	Bellows
1.4.1.2.1.2.9	Misc. Vacuum Fittings
1.4.1.2.1.2.10	Tools & Test Equipment
1.4.1.2.1.3	**ID Front End Controls and Monitoring**
1.4.1.2.1.3.1	Drivers, Controls and Electronics
1.4.1.2.1.3.2	Computers
1.4.1.2.1.3.3	Operator Interface
1.4.1.2.1.3.4	Video Monitoring System
1.4.1.2.1.3.5	Controllers & Interfaces for Field Devices
1.4.1.2.1.3.6	Printers
1.4.1.2.1.3.7	Test Equipment and Support Instrumentation
1.4.1.2.1.3.8	Tools
1.4.1.2.1.3.9	Cable Trays

1.4.1.2.1.4 ID Front End Controls and Safety Interlocks

1.4.1.2.1.4.1 PLC Hardware for Equipment Protection
1.4.1.2.1.4.2 PLC Hardware for Personnel Safety
1.4.1.2.1.4.3 PLC Software
1.4.1.2.1.4.4 Controllers & Interfaces for Field Devices
1.4.1.2.1.4.5 Uninterruptible Power Supplies
1.4.1.2.1.4.6 Interface to Accelerator SIS
1.4.1.2.1.4.7 Test and Diagnostics Station
1.4.1.2.1.4.8 Test Equipment and Support Instrumentation
1.4.1.2.1.4.9 Tools
1.4.1.2.1.4.10 Cable Trays

1.4.1.2.1.5 Survey and Alignment

1.4.1.2.1.6 Power and Utilities

1.4.1.2.2 BM Front Ends

1.4.1.2.2.1 Front End Component Assemblies

1.4.1.2.2.1.1 Fixed Mask Assembly and Enclosures
1.4.1.2.2.1.2 Lead Collimators and Housing
1.4.1.2.2.1.3 Photon Shutters, Enclosures and Monitoring
1.4.1.2.2.1.4 Photon Beam Position Monitor Assembly and Enclosures
1.4.1.2.2.1.5 Safety Shutter Assembly
1.4.1.2.2.1.6 Be Window Assembly

1.4.1.2.2.2 BM Front End Vacuum

1.4.1.2.2.2.1 Pumps
1.4.1.2.2.2.2 Isolation Valve
1.4.1.2.2.2.3 Fast Valve and Monitoring
1.4.1.2.2.2.4 Slow Valve
1.4.1.2.2.2.5 Vacuum Monitoring Equipment
1.4.1.2.2.2.6 Bakeout System
1.4.1.2.2.2.7 Vacuum Flanges and Beam Pipes
1.4.1.2.2.2.8 Bellows
1.4.1.2.2.2.9 Misc. Vacuum Fittings
1.4.1.2.2.2.10 Tools & Test Equipment

1.4.1.2.2.3 BM Front End Controls and Monitoring

1.4.1.2.2.3.1 Drivers, Controls and Electronics
1.4.1.2.2.3.2 Computers
1.4.1.2.2.3.3 Operator Interface
1.4.1.2.2.3.4 Video Monitoring System
1.4.1.2.2.3.5 Controllers & Interfaces for Field Devices
1.4.1.2.2.3.6 Printers

1.4.1.2.2.3.7 Test Equipment and Support Instrumentation
1.4.1.2.2.3.8 Tools
1.4.1.2.2.3.9 Cable Trays

1.4.1.2.2.4 BM Front End Controls and Safety Interlocks

1.4.1.2.2.4.1 PLC Hardware for Equipment Protection
1.4.1.2.2.4.2 PLC Hardware for Personnel Safety
1.4.1.2.2.4.3 PLC Software
1.4.1.2.2.4.4 Controllers & Interfaces for Field Devices
1.4.1.2.2.4.5 Uninterruptible Power Supplies
1.4.1.2.2.4.6 Interface to Accelerator SIS
1.4.1.2.2.4.7 Test and Diagnostics Station
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1.4.1.2.2.4.9 Tools
1.4.1.2.2.4.10 Cable Trays

1.4.1.2.2.5 Survey and Alignment

1.4.1.2.2.6 Power and Utilities

1.4.1.2.3 Front End Supports

1.4.1.2.3.1 Front End Support Table and Stages
1.4.1.2.3.2 Front End Support Tables and Kinematic Mounts
1.4.1.2.3.3 Beam Position Monitor Support
1.4.1.2.3.4 Beam Pipe Support
1.4.1.2.3.5 Support System Test Station
1.4.1.2.3.6 Beam Position Monitor Calibration System